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THE LOSSES IN CABLES AT HIGH FREQUENCIES.*

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When current passes through solid metal conductors at the high frequencies employed in wireless telegraphy and telephony the heat-losses are needlessly excessive, and, to diminish these, various types of stranded cable are employed. The object of this investigation is to *experimentally* determine if there is any appreciable difference in the losses in cables which depends upon the arrangement, the size, and the insulation of the individual strands which make up a cable, and to determine what combinations of these various features will give a cable best suited for use at high frequencies under specified conditions.

The high-frequency resistance of a given length of cable depends upon many variables, among which are the following:

The specific resistance of the wire.

The shape of the cross-section of the cable.

* Communicated by E. F. Northrup. The material of this investigation was obtained by R. G. Thompson and C. G. Monteiro for their theses leading to the degree of E. E. from Princeton University. The methods and planning of the research are due to E. F. Northrup. The presentation here given was prepared jointly by E. F. Northrup and R. G. Thompson.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the Journal.]

The dimensions of the cross-section of the cable.

The number of strands per unit cross-section of the cable.

The ratio of the cross-section of the copper in the cross-section of the cable to the total cross-section of the cable.

The type of stranding or braiding.

The type of winding in respect to twisting of the strands.

The type of winding in respect to inductive or non-inductive winding.

Owing to the variety and the complexity of the arrangements of strands employed in cables and the many variables which determine the resistance of cables to the passage of high-frequency currents, mathematical calculation of the power-loss or the resistance for any particular cable at a given high frequency is practically impossible. It is possible, however, to experimentally investigate these quantities for selected types of cables which may be taken as typical of those which are used in the construction of high-frequency apparatus. The authors are not aware of the existence of any exact experimental data on the losses of different kinds of cables at high frequencies which might aid in the selection of the best type of cable for a particular purpose.

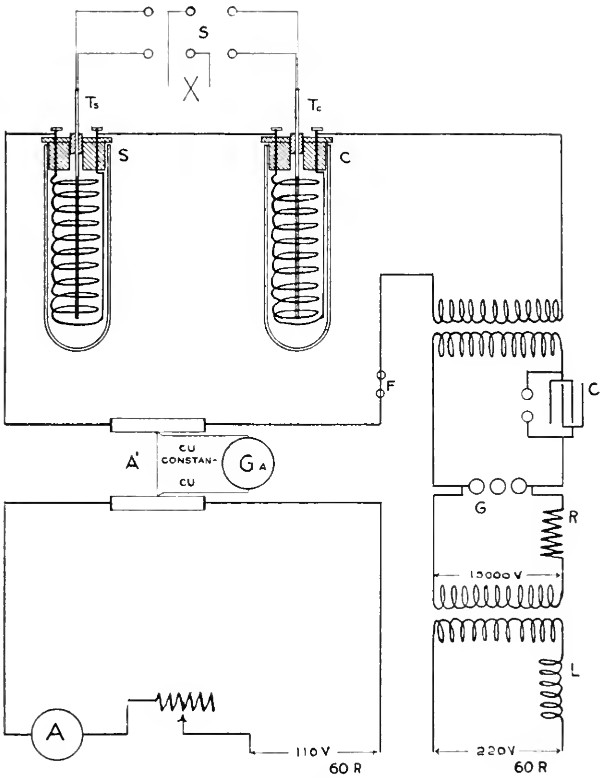
Stranded cables are much used for the secondary windings of the high-tension transformers employed in radio work, and this fact gives any reliable experimental data commercial value. In what follows we have attempted to supply such data by giving the results of a series of tests conducted with *great care* on several types of copper-wire cable. We have investigated for each of these cables both the *actual* and the *relative* losses for known high frequencies and known effective currents. We have, however, recorded only relative losses in the table of results. Where relative losses are considered, solid round-copper wire has been selected as a standard for making the comparisons. Sufficient data are given, however, so that the absolute losses in the cables of particular sizes and types tested can be calculated without reference to a solid-wire standard.

DESCRIPTION OF TESTS.

At the frequencies employed it may be safely assumed that all the losses in a conductor carrying an electric current are manifested as heat; hence, in comparing the different types of cable, a method was adopted whereby the relative and the absolute heat-

losses of different samples of cables could be measured. Equal lengths of solid wire and cable having very approximately the same cross-section were wound in coils and immersed in kerosene in Dewar bulbs, as shown in Fig. 1. These bulbs held each about 1.2 litres. The high-frequency current was obtained by means of a

FIG. 1.



Connections for high-frequency test.

circuit, arranged as shown in Fig. 1, which is an ordinary inductively coupled sending-station circuit as used in wireless telegraphy.[1] *

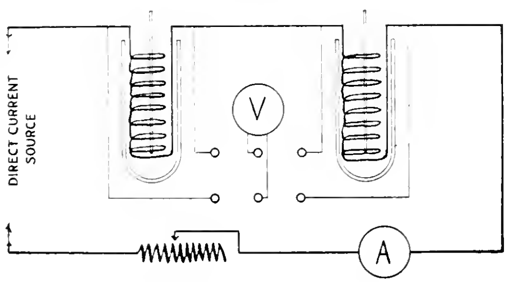
An inductive coupling was used in order that all the current in the secondary would be high-frequency. This current was measured by comparing it with measured low-frequency current, the

[1] * Reference numbers refer to the bibliography at end of paper.

equality of the currents being made known by means of a thermocouple (Fig. 1, A'), and the temperatures of the bulbs were measured with resistance thermometers, T_s and T_c.

After the coils had been sealed in the bulbs they were allowed to stand for at least two hours in order that the whole contents might come to room temperature. The high-frequency current was then passed through the coils, in some cases wound inductively and in others non-inductively, joined in series, the time of run being 22 minutes for the non-inductive coils and 45 minutes for the inductive. The inductance added to the circuit, when coils wound in the form of helices were tested, decreased the value of the current; hence in this case the time of run had to be made longer to get a satisfactory temperature rise. Readings were taken of time, current, and temperature rise for each bulb. The current

FIG. 2.



Connections for direct-current test.

readings were taken every two minutes, and the average of all these values for the run was used in the computation. After the high-frequency test, the bulbs were allowed to stand undisturbed until they again came to room temperature, which generally required about twelve hours.

Connections were next made as shown in Fig. 2 and a direct-current test made, the time of run being the same as in the high-frequency test. The value of the direct current was kept constant throughout the run, and so chosen that the temperature rise in the bulb containing the solid-wire coil was about the same as that obtained in the high-frequency test. Readings were taken of time, current, temperature, and voltage drop across each coil. Readings of voltage drop across each coil were taken every five minutes, the average voltage during the run being used in the

computations. For every high-frequency test a direct-current test was made, as it was necessary to determine the constants of the bulbs every time the coils were changed.

From the direct-current test the watt input for a given time, and thereby the watt-minute input per degree rise in temperature, was obtained for each bulb. From these data the watt-minute input was calculated for each bulb for the high-frequency test. The ratio of the watt-minute input for the bulb containing the cable coil to the watt-minute input for the bulb containing the solid-wire coil is the true ratio of the losses in the two coils.

Two solid-wire coils wound with wire of the same length and resistance were used as standards in making all the tests. Two coils of each kind of cable wire were also wound. In testing a certain cable, four complete tests were made, using the four coils in different combinations. The procedure practically eliminates the possibility of error in the final results obtained due to any inherent defects, such as a short circuit, in the coils themselves; for it is not probable that the same defect would be found in each of two coils. Hence when the four tests checked with each other within 2 per cent. it was assumed that the result was correct. For each cable the loss was measured for both inductive and non-inductive windings.

After the direct-current test, the bulbs were again allowed to cool and a 60-cycle alternating-current test was made, using the same value of current as in the direct-current test. Readings were taken of the time, current, and temperature, and the computations were made in the same manner as in the high-frequency test.

In all the tests the length of wire in the different coils tested was the same; the same oil was used for all the tests, and the same amount of oil was used in each bulb, because at high frequencies the losses in different oils are not the same.

The specific direct-current resistance was assumed to be the same for all the samples tested.

The same standards of No. 12 solid wire were used when testing all the cables, and the cross-section of all the cables was approximately that of the standards with which they were compared.

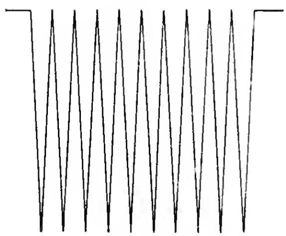
The conditions were the same for all the tests. All tests were started with the bulbs at room temperature to eliminate errors due to radiation. These errors would, however, be very small in any

case where a cable in one bulb is compared with a solid wire in a very similar bulb.

DESCRIPTION OF APPARATUS.

Coils.—The length of wire used in each coil was 64.5 feet, as this was the amount found to be most convenient for making coils of a size suitable for the Dewar bulb. The coil was formed by winding the wire around a paraffin-coated cylinder of brass, 2½ inches in diameter. The axial length of the coil was made 1 foot. The coil, after being wound, was removed from the metal winding-form before it was tested. The type of non-inductive winding used is shown in Fig. 3. Of all types of non-inductive winding which might have been used in the tests, this type has the least electrostatic capacity. The inductive coils were wound on the same cylinders

FIG. 3.



Winding for non-inductive coils, shown developed from a cylinder.

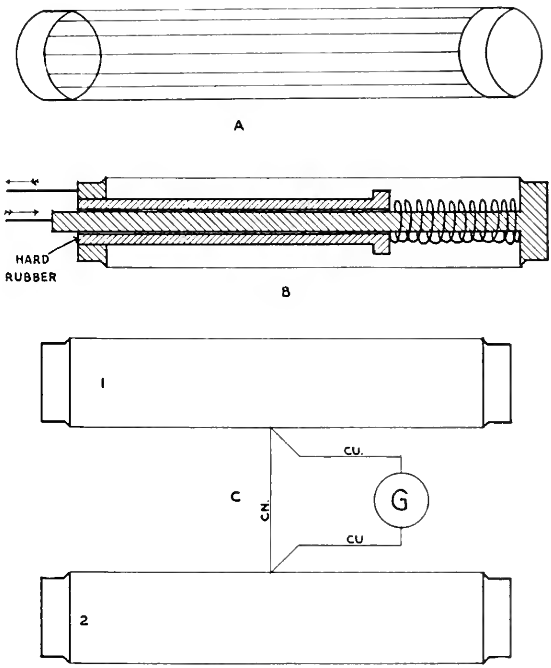
in the form of one-layer helices. After winding the coil on the cylinder, it was baked at 100° C. for a few hours, then soaked for three hours in an insulating varnish commercially used for impregnation, and baked again at 100° C. until dry. The coil was then soaked and baked again. The cable-coil was treated in this manner in order that the varnish might soak in and insulate one strand from another as much as possible. After baking the coils, the cylinder was removed and the terminals of the coil were soldered to the connections at the lower part of a wooden top which fitted into the Dewar bulb (Fig. 1). The wooden top was sealed to the bulb with hot paraffin. Particular care was taken in each test to see that the coil was totally immersed in the kerosene.

Dewar Bulbs.—The Dewar bulbs used for the tests were *unsilvered.* They were 15 inches long and 4 inches in diameter.

No difference in results could be obtained by interchanging the bulbs, and they were found to have the same cooling constants. The vacuum of the Dewar flask was very good, as was proved by the fact that no electrodeless discharge was observed in any of the tests.

Silvered Dewar bulbs cannot be used for tests of this character. It was found by trial that a silver coating makes a secondary cir-

FIG. 4.



High-frequency ammeter.

cuit in which currents are induced when a helix within the bulb carries high-frequency current. The heat developed in the silver coating was comparable with the heat developed in the coil itself.

HIGH-FREQUENCY AMMETER.[3]

The type of ammeter employed for measuring the high-frequency current will be understood by reference to Fig. 4. About twelve wires of manganin were disposed on the circumference of a

cylinder, running lengthwise of the cylinder and equally spaced from each other (Fig. 4, *A*). Low-frequency or high-frequency current will be conducted through a set of wires thus arranged in the same manner. These wires were attached at each end to brass disks. A spring arrangement (shown in *B*, Fig. 4) maintained them taut. Current was led in to one end of the wires along the axis of the cylinder. The combination as a whole was thus non-inductive. Two of these cylinders, made exactly alike in all respects, were constructed. One of these cylinders, which we shall call a spool, carried the high-frequency current and the other the comparison current. When the current through each of the spools has the same effective value the heating effect of the current of each spool is the same, not only for the spool as a whole but for each individual wire. By connecting together near the middle point one wire of each spool with a piece of very fine constantan wire, and also fastening at the points of junction fine copper wires, a thermocouple is made which, connected to a sensitive galvanometer, gives a very delicate indicator of the condition that the two spools are carrying currents of equal heating effects. As this type of high-frequency ammeter proved both convenient to use and accurate, and as it can be constructed for carrying currents of any magnitude, we give some further details of the construction of the one we employed.

The wires used for each spool were No. 38 manganin wire and twelve in number. The length of the wires, or the distance between brass-end pieces of a spool, was 3½ inches. Care was taken to solder the wires in such a manner that each one had the same length and resistance.

The procedure in measuring the high-frequency current consisted in passing this current through spool No. 1 (Fig. 4, *C*), and 60-cycle alternating current in series, through an ammeter, an adjustable rheostat, and spool No. 2, and varying this latter current until the galvanometer attached to the thermocouple gave no deflection. When this adjustment is made both junctions of the thermocouple are at the same temperature and, assuming the spools are identical and under like conditions in respect to loss of heat, the effective values of the high-frequency current and the low-frequency comparison current are the same. An accurate alternating-current ammeter permitted the reading of this latter current with precision. Sixty-cycle alternating current instead

of direct current was employed as a comparison current, for the reason that when direct current is used some of this direct current finds its way through the galvanometer with the best attachments of the thermocouple junctions to the wires which it is practical to make. This difficulty is avoided by the use of the alternating current.

While it is impossible to make two spools which are in all respects identical and which lose their heat at the same rate, the lack of symmetry was provided for and made to have no influence by shunting the spool of higher resistance until, on the passage of equal measured currents of low frequency through each spool, the galvanometer deflection was reduced to zero. In using the meter for measuring the high-frequency current the low-frequency current was passed through the shunted spool, because a low-frequency current will divide between the wires of the spool and the shunt according to Ohm's law, while high-frequency current will not so divide. To insure uniformity in its performance the meter was mounted in a tin box and immersed in paraffin oil. For all the experimental data obtained it was assumed that the error in measuring the effective value of the high-frequency current did not exceed 5 per cent.

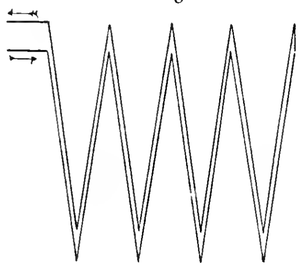
RESISTANCE THERMOMETERS.

It was found by using a mercury thermometer that the temperature in the bulbs, while the test was in progress, was not the same at different levels of the oil in the bulb. The maximum difference was about 0.5° C. It was further found that when the tests were made on inductively-wound coils at the high frequency used a current was induced in the mercury in the thermometer bulb. The magnitude of this current and its heating effect were such that readings taken with a mercury thermometer were worthless. To avoid this latter difficulty and also to be able to obtain at a single reading the average temperature of the oil from its bottom to its top layer, two carefully-constructed resistance thermometers were made as follows:

Copper wire was selected for the thermometers because over moderate ranges of temperature its resistance increases linearly with the temperature. Each thermometer was made of 385 feet of No. 36 B. & S. silk-covered wire. The type of winding was adopted which would make the thermometer strictly non-inductive,

as it must be when used in the presence of high-frequency current. The wire was doubled once on itself and then looped up in the form of a skein, the length of the skein being made about equal to the depth of the oil. The development of the winding is shown in Fig. 5. This wire skein was then "aged" by heating in a gas oven at 140° C. for twelve hours. A skein was then slipped into a thin-walled glass tube, 16½ inches long and ¼ inch outside diameter, and closed at the bottom. The completed thermometers were adjusted under identical temperature conditions until their resistances were like each other to within 0.01 of 1 per cent. The resistance of each thermometer was 159.43 ohms at 21.2° C. After the resistances had been adjusted the thermometers were completed by filling the tubes with paraffin.

FIG. 5



Winding for resistance thermometers.

The resistances of the thermometers were measured by means of a very accurate Leeds & Northrup Wheatstone bridge, a ratio of 1000 to 100 being used in the bridge. Connections were made with a mercury-contact switch (Fig. 1, *S*), and the resistance of the leads from the thermometers to the bridge was entirely negligible. The measuring current through the thermometers was reduced until its heating effect was entirely negligible. Readings of resistance were accurately determined, relatively to each other, to 0.01 ohm, and this determined changes in the temperature of each bulb to 0.01° C. The temperatures were taken from a previously-drawn curve giving the straight-line relation between resistance and temperature.

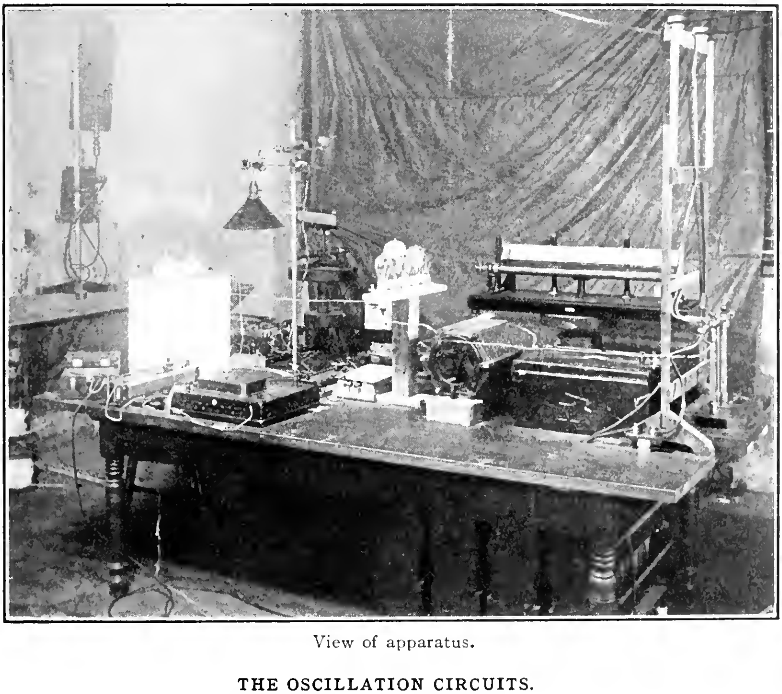
As the skeins forming the thermometers equalled in length the coils tested, and were only a little less in length than the depth of the oil in the bulb, a single temperature reading gives the mean temperature on the interior of the bulb. The coils tested and the

length of the thermometer skeins was about 12 inches. The carefully-made non-inductive winding employed in the thermometers prevented any development of heat in the thermometers from induced currents at the highest frequencies used.

WAVE-METER.[4]

All determinations of frequency were made with a wave-meter which was kindly loaned for this investigation by the American Transformer Company.

FIG. 6.



View of apparatus.

THE OSCILLATION CIRCUITS.

Certain devices were employed to obtain continuous and uniform sparking at the double spark-gap G (Fig. 1). A resistance R of 40,000 ohms was inserted in the high-tension side of the transformer. This has the effect of limiting the condenser charging current so that *one and only one* spark passes at the gap G for each half-cycle of the primary current. The regularity of the discharges at the gap G was further improved by the insertion

of a large inductance L in the primary circuit of the transformer and also by blowing a jet of air on each gap of the double spark-gap.

Incidentally, the above adjustments can be used effectively for obtaining uniformly-timed very brilliant discharges for instantaneous photography of the most rapidly moving objects.

(For an application of this method to photography see "An Experimental Study of Vortex Motions in Liquids," by E. F. Northrup, JOURNAL OF THE FRANKLIN INSTITUTE, September and October, 1911.)

Description of Cable Tested.

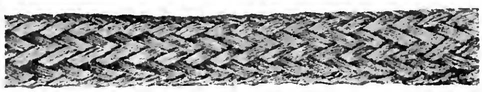
No.	Type	Size of wires	Number of wires	Cross-section, c.m.	Diameter, t.c.c.	Equivalent B.S.	Pounds per 1000 feet
1.	Parallel	30	65	6533	0.103	12	19.50
2.	Twisted	30	65	6533	0.125	12	21.50
3.	Stranded	36	238	5950	0.116	12–13	18.88
4.	Hawser lay	36	231	5775	0.118	12–13	17.87
5.	Braided	36	240	6000	[0.097 x 0.177]	12–13	19.63
6.	Enamelled	36	259	6475	0.108	12	20.72
7.	High-frequency	28	24	3840	0.108	14	11 52
	Solid	12	1	6530	0.103	12	19 77
	Solid	14	1	4107	0.082	14	12.44

Illustrations of some of the cables are given in Fig. 7.

FIG. 7.

Cable No. 4.

Cable Nos. 3, 6 and 7.



Cable No. 5.

Types of cables tested.

Cable No. 1.—In this cable all the strands are parallel.

Cable No. 2.—This cable was made from Cable No. 1 by twisting a length of 70 feet about 1200 times, which shortened this length to 64.5 feet.

Cable No. 3.—Thirty-four No. 36 wires are twisted together. Seven of these strands are then cabled around each other in the ordinary rope-weave.

Cable No. 4.—Eleven No. 36 wires are twisted together in small strands. Three of these small strands are then cabled around each other. Seven of these larger strands are then cabled around each other, which gives a hawser rope-weave.

Cable No. 5.—This cable is made by braiding together twenty-four strands, each strand consisting of ten No. 36 wires. The cross-section is rectangular.

Cable No. 6.—Thirty-seven No. 36 enamelled wires are twisted together. Seven of these strands are then cabled around each other in the ordinary rope-weave.

Cable No. 7.—Four strands of No. 28 enamelled wire are twisted together and covered with a wrap of Tussah floss. Six of these strands are then cabled around a core of hemp.

Cables No. 6 and No. 7 are insulated with a silk covering; all the rest of the cables are insulated with a (t.c.c.) triple-cotton covering.

With the exception of Cable No. 5, the cross-section of all the cables was circular.

The enamel insulation on Cables No. 6 and No. 7 is said to stand a breakdown test of from 400 to 600 volts alternating. All the rest of the cables were made of bare wire and treated with an insulating varnish.

RESULTS OBTAINED IN THE MEASUREMENTS.

Results obtained in our measurements are given below in tabulated form. The precise meaning and the significance of the different numerical quantities given in the table of results will be clearly understood from the following definitions of the symbols we have employed and the simple relations between these symbols, used to express the meaning of the tabulated quantities:

Symbols: High-frequency Test:

t = time in minutes, = total time of a single test.
$(I)^2$ = square of high-frequency current in ampères.
T' = rise of temperature of bulb in degrees C.

Direct-current Test:

t = total time of test in minutes.
I = current in ampères.
$E = IR$ = mean voltage drop during test at terminals of coil.
T = rise in temperature of bulb in degrees C.

In both the high-frequency and direct-current tests the temperature at the time of starting the tests was room temperature, and the rise of temperature, T' or T, is the degrees rise above room temperature.

Relations Employed in Expressing Results: Direct-current Test:

$W =$ total watt-minute input $= EIt$.
$w =$ watt-minute input per degree rise $= W/T$.
$R =$ ohmic resistance of coil $= E/I$.

High-frequency Test:

$W' =$ total watt-minute input $= wT' = (I')^2R't$.
$R' =$ high-frequency resistance of coil $= W'/(I')^2t$.

1. Ratio of high-frequency resistance of cable to high-frequency resistance of standard $= R'_c/R'_s$.

(The subscript c is used in each case when the quantity refers to a cable coil, and the subscript s when it refers to a solid-wire coil.)

$$\frac{R'_c}{R'_s} = \frac{(I')^2R'_ct}{(I')^2R'_st} = \frac{w_c\,T'_c}{w_s\,T'_s} = \frac{W'_c}{W'_s}.$$

2. Ratio of high-frequency resistance to direct-current resistance of a coil $= R'/R$.

$$\frac{R'_c}{R_c} = \frac{(I')^2R'_ct}{I^2R_ct} = \frac{W'_c}{W_c}.$$

3. Expressions for the ratio, $\dfrac{R'_c/R_c}{R'_s/R_s}$.

$$\frac{R'_c/R_c}{R'_s/R_s} = \frac{R'_c}{R'_s}\times\frac{R_s}{R_c} = \frac{(I')^2R'_ct}{(I')^2R'_st}\times\frac{I^2R_st}{I^2R_ct} = \frac{w_cT'_c}{w_sT'_s}\times\frac{w_sT_s}{w_cT_c} = \frac{W'_c}{W'_s}\times\frac{W_s}{W_c} = \frac{T'_c}{T'_s}\times\frac{T_s}{T_c}$$

TABLE OF RESULTS.

NON-INDUCTIVE TESTS.

Cable	R_c/R_s	R'_c/R'_s	$\dfrac{R'_c/R_c}{R'_s/R_s}$
1	1.07	1.11	1.06
3	1.22	1.09	.88
4	1.25	.86	.68
5	1.21	.50	.41
6	1.14	.48	.42
7	1.13	.64	.57
Solid, No. 14	1.00	1.00	1.00

INDUCTIVE TESTS.

1	1.01	1.42	1.41
2	1.34	.85	.70
3	1.19	.65	.55
4	1.24	.62	.48
5	1.21	1.11	.92
6	1.24	.36	.29
7	1.92	.61	.32
Solid, No. 12	1.00	1.00	1.00

COMMENTS ON THE TESTS AND THE DATA.

The method employed in obtaining the above tabulated results was entirely experimental and was so devised that no correction factors are required. An examination of the method employed in calculating the results which are recorded above will show that the accuracy of all these relative values is independent of the current measurements. The precision rests only on the measurements of temperature, as all other factors entering the computations cancel out. We believe the final results are accurate to a degree that the maximum variation from the mean obtained in any of the tests on the various cables does not exceed 2 per cent.

The copper cables selected for the tests were chosen from among those which are largely used commercially, especially in the secondary windings of high-tension transformers designed for radio work.

The frequency obtained and used in the tests on the non-inductively wound coils was 250,000 cycles, and the effective value of the high-frequency current obtained and measured as above described was 10.5 ampères. When the coils being tested were wound inductively the inductance, added to the secondary winding of the oscillating circuit, changed the constants of the circuit so that the frequency then became 167,000 cycles and the effective value of the current became reduced to 4 ampères.

When the direct-current tests were made, to determine the constants of the bulbs and their contents, it was found that 19.5 ampères direct current was required to produce the same temperature rise in the same time as that obtained in the high-frequency test, provided non-inductive coils were used, and 9 ampères when inductive coils were used.

When in the high-frequency tests the non-inductive coils were short-circuited the measured high-frequency current was increased about 10 per cent. As the ohmic resistance of the coils was very

small, this indicates that even in the non-inductively wound coils there still remained an appreciable inductance. This may be in part accounted for by the internal magnetic field which exists in every conductor and which no non-inductive winding can eliminate.

The non-inductive coils of cable No. 7 were compared with similarly wound coils made of No. 14 B. & S. solid wire, while the inductively wound coils were compared with similarly wound coils of No. 12 B. & S. solid wire.

The fact that cable No. 1, the strands of which run parallel, heats more than a solid wire of very approximately the same diameter is noteworthy.

The effect of the shape of the cross-section of the conductor on the heat loss is well shown in the tests made on cable No. 5, the cross-section of which was rectangular.

A test was made to compare the losses in two solid-wire coils, one being wound inductively and one non-inductively. The two coils compared were two of the standard coils of No. 12 wire, the one being wound non-inductively and the other being wound in the form of a one-layer helix. The loss in the helix was 2.1 times the loss in the non-inductively wound coil. This rather surprising result may possibly be accounted for by the surging in and out of current in the distributed capacity of the inductive coil, which probably greatly differed from that of the non-inductive coil.

Tests with 60-cycle alternating current were made on all the cables, and with this low frequency no difference could be found between the loss in a cable and the loss in a solid wire, provided the direct-current resistances of both were the same.

CONCLUSIONS.

The following conclusions may be drawn from these tests:

In a cable the strands of which are parallel the loss is appreciably greater than it is in a solid wire having the same cross-section; and, surprising as it may appear, if this same cable is very much twisted, so that the wires lie in concentric spirals, the loss decreases 50 per cent. or more and becomes less than in a solid wire. The tests appear to show that the more the cable is twisted the greater is the reduction in the loss.

With the exception of the case just mentioned, the alternating-current resistance of a cable is less that that of a solid wire of the

same cross-section. The smaller the individual wires and the better they are stranded or braided and the more perfectly they are insulated from each other, the more nearly does the alternating-current resistance approach the direct-current resistance for a given cable. It is, further, important that individual wires should be stranded or braided so that in passing along the cable an outside wire becomes an inside wire, and then again *vice versa*.

Well-insulated cable-strands are obtained by using enamelled wire, though good insulation may be partially obtained by thoroughly treating the cable with an insulating varnish. Our tests seemed to indicate that the decrease in loss obtained by using enamel-insulated wire in cables would hardly warrant the extra cost of this kind of insulation, particularly in cases where only a portion of the total current which flows is high-frequency current. A case of this character is where the secondary of a high-tension transformer feeds an oscillating circuit, some of the high-frequency oscillating current finding its way into the secondary winding of the transformer.

The phenomena which we have attempted to examine experimentally are so exceedingly complicated and are dependent upon so many variables that full explanations of their causes or the drawing of general conclusions are practically impossible. It is hoped, however, that the method here described will enable others, by employing it, to obtain specially-desired data for particular cases and, also, that enough data on typical types of cables are here given to be of much assistance to the designer of high-frequency apparatus in making a selection of a particular type of cable best suited to meet special requirements.

The writers of this paper wish to express their indebtedness to Mr. C. G. Monteiro for the full share which he had in the experimental work and in the taking of the observations.

BOOKS AND ARTICLES REFERRED TO.

[1] George W. Pierce, "Principles of Wireless Telegraphy," chapters 20–21.

[2] J. J. Thomson, "Electricity and Magnetism."

[3] J. H. Dellenger, "High-frequency Ammeters," Reprint No. 206, *Bulletin U. S. Bureau of Standards.*

[4] George W. Pierce, "Principles of Wireless Telegraphy," p. 220.

[5] Edwin F. Northrup and John R. Carson, "The Skin Effect and Alternating-current Resistance," JOURNAL OF THE FRANKLIN INSTITUTE, February, 1914.

PALMER PHYSICAL LABORATORY, Princeton, N. J.,
March 27, 1916.

The Sanitation of Railway Cars—Ventilation. T. R. CROWDER. (*Proceedings of the New York Railroad Club,* April 21, 1916.)—Ventilation is a vital sanitary problem. Good air is of prime importance to good health. Ten or twelve years ago attempts to supply good air to railway cars were generally failures. The problem seemed complicated and almost hopeless. It still has its difficult points, but, thanks to the enlightening research of the last ten years, it is much simplified. We have learned what good air is: it is air that bears a proper thermic relation to the body. It must be able to absorb the body heat as rapidly as formed, without being cold enough to produce chilling. It must be warm, but not too warm; it must have motion, but not enough to cause discomfort; it must be changed occasionally to prevent stagnation and overheating. When these conditions, which are purely physical, are complied with, practically all other things may be left out of consideration. The chemical changes brought about by respiration are ordinarily negligible.

Due to the high wind pressure to which running trains are constantly subjected, a surprising amount of air enters them, even when no special provision is made for it. Apparently the quantity can always be kept adequate by the application of a simple exhaust system, as is now done on many lines. A more difficult problem than maintaining the air supply is the proper control of heat. If the temperature is carefully regulated to between 65° and 70° F., complaint of poor ventilation will seldom arise, even with impure air and a very small supply. Above 70°, trouble comes quickly; we think there is not enough air to keep our lungs flushed out. This is not the trouble at all, for let the air supply remain unaltered and the temperature drop to the lower sixties and we think there is too much. The income and outgo create air motion within. When the temperature is high we need more motion, hence a larger air supply to keep the body cool; when it is low we need less motion, or a lower air supply. But the lungs and the function of respiration have nothing to do with this; it is entirely a surface function; and that is what ventilation is for—to act on the surface of the body and carry away its heat. That is what a fan does, and we all know the virtues of a fan.

With a simple exhaust system of ventilation, specific air inlets are not necessary unless the cars are greatly crowded. Natural crevices, to which may be added open sashes in the end doors, will be sufficient. For supplying artificial heat, direct radiation is better than indirect. Little cold streams of incoming air, mixing with the warmer and stiller body of air within, contribute to the stimulating variation of surface environment which are necessary to comfort and health. Only when larger quantities of air are admitted at one place is heating of the incoming stream desirable, and this is not a good plan for ventilating railway cars. When no artificial heat is needed, as in the warm summer months, nothing can take the place of open windows; for large streams of rapidly moving air are necessary to maintain the thermic balance of the body.

SOME PROBLEMS IN PHYSICAL METALLURGY AT THE BUREAU OF STANDARDS.*

BY

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INTRODUCTION.

THE available knowledge concerning the properties of metals and alloys and the dependence of these properties upon what we may call the life-history of these metals, including their pedigree, or preparation and composition, and conditions of birth, or their manufacture, is all too meagre, both in quantity and quality.

Thus Prof. H. Le Chatelier, who compiled the data on metallic alloys for the Table of Physical Constants recently published by the French Physical Society, prefaces his compilation with the following remarks:

"Concerning the physical properties of alloys, it is impossible to find numerical data worthy of any confidence. This comes from the fact that, on the one hand, experiments have been made by physicists too disdainful of chemical analysis, and, on the other hand, by chemists unfamiliar with physical measurements. It would be impossible in some cases to repeat, to within 50 per cent., results which were measured nevertheless with a precision of one in a thousand, on account of lack of sufficient indications as to the composition of the alloy studied; again, several measurements made on alloys of exactly determined composition do not agree among themselves to 10 per cent. It is practically only for the melting-points of alloys that we possess somewhat accurate information."

This statement by Prof. Le Chatelier is by no means an exaggeration, and that such conditions as he describes with respect to the metallic alloys may exist appears to be due, in part at least, to the isolation and specialization of investigations, and to a lack of appreciation of the importance of the history of the materials

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* Presented for Dr. Burgess at a meeting of the Mining and Metallurgical Section held Thursday, March 30, 1916, by Dr. Paul D. Merica.

which are being studied. How many precise physical measurements, for example, have been made on material described merely as "iron," the results of which are oftentimes meaningless because of lack of a sufficient and necessary knowledge of chemical composition, mechanical treatment, and thermal history?

TABLE I.

Investigation and Testing of Metals at Bureau of Standards.

PUBLICATIONS: T = Technologic Paper, S = Scientific Paper, C = Circular of Information; referred to by number.

A. MATERIALS .... C 45	1. *Metallic Elements:* Iron, nickel, copper, zinc, etc. 2. *Alloys:* *a.* Two components: Iron-carbon (steels), copper-zinc (brasses), etc. *b.* Three or more components: Alloy steels, complex bronzes and brasses, etc. *c.* Commercial metal alloy products. 3. *Plated Metals:* Galvanized iron, copper and nickel plating, etc. 4. *Auxiliary Products:* Metallurgical slags, fire-clays, moulding sands, deoxidizers, etc. C 45; T 10. 5. *Apparatus:* Instruments, manufacturing accessories, furnaces, etc. S 219.
B. METHODS:	
1. Preparation illustrated by:	*a. Production of Pure Metals:* Examples, electrolytic iron, gallium, etc. S 263. *b. Standards for Pyrometry,* Electricity, chemical analysis, metallography, etc. S 107, 143, 194, 195, 256; C 1, 2, 3, 7, 14, 18, 25, 26. *c. Mixing Pure Metals* (in foundry and laboratory): Examples, pure iron-carbon series, Government bronze (88 Cu – 10 Sn – 2 Zn), etc. T 59. *d. Treatment of Alloys:* Thermal, chemical, mechanical, magnetic, electric, etc. C 6, 17, 42; T 60. *e. Commercial Samples,* including methods of sampling. *f. Coöperative Production and Tests on a Commercial Scale:* Examples, ingots for rails, structural brasses and bronzes, statuary bronze, moulding sands, test ingots of steel, etc.
2. Constitution as determined by: C 42	*a. Chemical Analysis:* Bureau is equipped for chemical analysis of all metal products: Example, segregation in steel and bronze ingots, T 6, 8, 24, 33, 69; S 161, 186; C 14, 25, 26, 42. *b. Thermal Analysis:* Heating and cooling curves for location of melting and critical points: Examples, alloy steels, new alloys, etc. S 99, 213; C 7. Variation of physical properties with temperature. *c. Microscopic Analysis* (*i.e.*, characteristic microstructure as determined by): 1. Chemical composition. 2. Thermal history. 3. Mechanical work, hot or cold. 4. Manufacturing methods. 5. Metallographic methods and apparatus, etching reagents, etc.; photomicrographs furnished.

2. Constitution as determined by: C 42
   - *d. Other Physical Methods of Examination:* Examples, expansion, thermo-electric, magnetic, spectroscopic, etc. S 19, 108, 109, 117, 120, 251.
     1. Thermo-electric determination of platinum purity. S 254, 280.
     2. Spectroscopic analysis for rare elements in steels.
   - *e. Nomenclature*
     1. Non-ferrous alloys.
     2. Constituents of steel.

3. Properties.....
   - *a. Chemical and Physico-chemical:* Examples, solubilities, attack by acids, improvement of analytical methods, etc. S 53, 82.
   - *b. Physical* at high, ordinary, and low temperatures:
     1. Mechanical.....
        - Density.
        - Hardness. T 11.
        - Fatigue.
        - Tensile, etc.
        - Elastic.
        - Torsion, shear, etc.
        - Bending.
        - Hydraulic.
     2. Thermal.......
        - Melting-point. S 62, 143, 205; C 35.
        - Critical point. C 7; S 236, 213.
        - Specific heat. S 231.
        - Heat of fusion.
        - Heat of vaporization.
        - Conductivity. S 68.
        - Expansion, etc.
     3. Electrical, magnetic, optical:
        - Capacity, etc. S 64; 252.
        - Resistance. S 73, 94, 124, 147, 148, 236.
        - Thermo-electric. S 229.
        - Susceptibility, etc. S 252.
        - Permeability. S 38, 78, 80.
        - Radiation. S 24, 40, 55, 105, 121, 128, 131, 156, 191.
        - Absorption.
        - Emissivity. S 97, 152, 196, 224, 242, 243.
        - Etc.
   - *c. Miscellaneous.* T 2, 15; C 58; S 272.
   - *d. Effect of Impurities:* Examples, occluded gases, slag, oxides, cadmium in brass, etc. T 6, 8, 24; S 161,
   - *e. Effects of Outside Agencies; i.e.,* pressure, magnetic field, etc.
   - *f. Corrosion...*
     1. Iron and steel.
     2. Brasses, etc.
     3. Structures. T 15.
     4. Electrolytic surveys of cities, etc. T 25, 26, 27, 28, 32, 52, 54, 55.

4. Applications...
   - *a. Built-up Structures:* Examples, bridge columns. T 2.
   - *b. Substitutes for More Costly Metals.*
   - *c. Miscellaneous Improvements.* C 50, 51, 52.
   - *d. Metals Best Adapted for Given Purpose.*
   - *e. Effect of Time in Testing Operations.*

5. Manufacturing processes
   - *Replies* to innumerable requests for information. T 38.

6. Metallurgical processes and treatments, such as theory and practice of:
   - a. *Annealing:* Examples, ordnance, bronzes, cast iron.
   - b. *Forging and Rolling:* Examples, rails, axles, etc.
   - c. *Tempering:* Example, springs.
   - d. *Quenching and Hardening:* Example, various steels.
   - e. *Cementation:* Example, automobile parts.
   - f. *Cold and Hot Working:* Examples, steels and bronzes.
   - g. *Casting:* Examples, rail ingots, various alloys.
   - h. *Plating, etc.:* Examples, copper, zinc, tin, nickel, etc.
   - i. *Alternating Stress.*
   - j. *Welding:* Examples, castings, rails.
   - k. *Miscellaneous:* Examples, finishing temperatures of rails. T 38. Coatings for metal structures.
7. Special problems, such as
   - a. *Electric Fuses.* T 74.
   - b. *Bonding of Rails.* T 62, 63.
   - c. *Improvement of Locomotive Springs.*
   - d. *Transverse Fissures in Rails,* investigated by (as example of methods used):
     1. Mechanical.
     2. Thermal.
     3. Optical.
     4. Chemical.
     5. Metallographic.
     6. Magnetic.
     7. Statistical.
     8. In coöperation with railroads.
8. Specifications for:
   - a. *Government Departments.*
   - b. *Cities, Commissions, etc.*
   - c. *In Coöperation with Technical Societies.*
   - d. *In Response to Private Requests.*
   - e. *Compilation of:* Examples, foreign specifications of railway materials. T 61.
9. Metal failures, determination of causes such as of:
   - a. *Railway Materials:* Rails, wheels, axles, etc.
   - b. *Castings:* Forgings, etc.
   - c. *Structural Bronzes and Brasses:* Examples, Catskill Aqueduct bronzes.
   - d. *Fusible Boiler Plugs,* for Steamboat-Inspection Service. T 53.
   - e. *Miscellaneous:* Boiler plates, tubes, galvanized ware, etc.
10. Testing: Includes items in all of above schedule.
11. Correspondence and advice given on all of above items.
12. Compilation of physical constants of metals.
13. Bureau serves as referee in disputes concerning metals.
14. Coöperation with technical and scientific societies, such as committees of:
   - a. *American Chemical Society.*
   - b. *American Society for Testing Materials.*
   - c. *American Foundrymen's Association.*
   - d. *American Institute of Metals.*
   - e. *American Electrochemical Society.*
   - f. *American Society of Civil Engineers.*
   - g. *American Institute of Mining Engineers.*
15. Metal Museum: *Exhibits of Metals.*

In planning an experimental attack on any comprehensive problem in physical metallurgy it is therefore essential to keep constantly in the foreground the interrelations of those various

factors dependent upon manufacture and previous history of the material studied; which is another way of saying that while physical metallurgy may be said to be that branch of science which treats of metals in their physical aspects, yet it takes cognizance also of chemical metallurgy—the only metallurgy of a few years ago—chemistry and physical chemistry including crystallography and metallography, and expresses itself largely in the language and uses the instruments of physics. At the Bureau of Standards, in planning our investigations of metals, we have striven, in so far as the several problems permitted, to treat them in such a manner that none of these essential factors or aspects is omitted.

In Table I is given a summary of the various activities relating to metals that have been executed or are being carried out at the Bureau. Each of the items mentioned has been or now is an object of experimental study on the part of one or another of the several scientific and technical divisions into which the Bureau, for administrative reasons, is divided.

It is, of course, not my intention to tax your patience with a detailed account of the progress made in all of these items of research, testing, specifications, and other matters relating to metals at the Bureau of Standards. As illustrative of our methods, however, I will venture to sketch, as briefly as possible, certain of these problems, with the solution of which it has been my privilege to have been, in some measure, personally identified.

PREPARATION AND PROPERTIES OF PURE IRON.

Iron, in its various alloyed forms, is perhaps the most commonly used of the metals, and yet few of us have even seen, and much less worked with, *pure* iron. It would appear to be almost axiomatic that for a comprehensive knowledge of the iron alloys it is first necessary to know with some exactness the properties of the major constituent, the iron itself. Yet here for this most common metal Le Chatelier's admonition is strikingly true: our knowledge of the physical properties of this ordinary and extraordinary chemical element is highly imperfect and very unsatisfactory.

To prepare this metal of a high degree of purity and determine at least some of its physical properties with exactness was, therefore, one of the first fundamental problems which the Bureau of Standards set itself in its study of metals. This is being followed by similar studies of the iron alloys of carbon, manganese, etc.,

free from the other contaminating elements usually, or practically always, present in such steels or alloys made by the ordinary industrial processes.

But it was soon found that in the preparation of strictly pure iron, say 99.97 per cent. Fe, it was no simple matter to eliminate certain of the impurities from this material and to prevent contamination by others. The iron deposited electrolytically, which was used as a basic material, can be broken in the hands, is cellular, and contains hydrogen; so the metal had to be heated and melted *in vacuo* to expel this and other gases. As no crucibles could be found on the market which were sufficiently free from silica to prevent contamination of the iron during the melting operation, methods had to be devised to make especially purified and calcined magnesia, which was then made up into crucibles to melt the iron in.[1] We are not yet sure regarding the oxygen content of this iron, which has indeed become a precious metal. A special study has, however, been begun of this puzzling question of the presence and significance of gases and oxides in iron and steels.

The pure iron thus made available, even in quantities of only a few grammes, can now be compelled to give an account of itself as to its several physical properties. This examination is under way, and the correct experimental bases for the answer to several questions long in dispute or doubt concerning the properties of pure iron have been laid in our laboratories or in others to which samples of the iron prepared at the Bureau of Standards have been sent.

Thus we have determined the melting-point of pure iron to be $1530° \pm 3°$ C.,[2] and have located with improved apparatus and described the thermal, critical ranges or transformations A_2 and A_3, at 768° C. and about 910° C., concerning the nature and very existence of A_2 at least, and the interpretation of which, in terms of allotropy, there has raged a discussion covering at least three decades.[3] The exact form of curve of variation of electrical resistance with temperature between 0° and 950° C. has been

[1] Cain, Schramm, and Cleaves, "Preparation of Pure Iron and Iron Carbon Alloys," B. S. Scientific Paper No. 266, 1915.

[2] Burgess and Waltenberg, "Melting-points of the Refractory Elements: I. Elements of Atomic Weight 48 to 59," B. S. Scientific Paper No. 205, 1913.

[3] Burgess and Crowe, "The Critical Ranges, A_2 and A_3, of Pure Iron," B. S. Scientific Paper No. 213, 1913.

measured with high accuracy,[4] and there is under way a study of the thermo-electric characteristics over the critical ranges A_2 and A_3, which confirms their separate existence and different nature. Measurements of the specific radiation for the solid and liquid over a wide temperature interval are among the other physical constants of iron thus far determined. The specific heat, heats of fusion and vaporization, and magnetic properties are waiting their turn with many others. In the hands of Professor Honda, of Japan; Professor Carpenter, of London, the staff of the Geophysical Laboratory, and several other investigators, this iron made by us is yielding other very interesting and valuable results.

APPLICATIONS OF THE MICROPYROMETER.

When dealing in investigation work with the more common metals, such as iron and copper, the difficulty hardly ever arises of scarcity of materials, such that our work with them may be carried out on specimens of as large size as desired. In the case, however, of certain metals and materials we may consider ourselves fortunate in being able to obtain even the smallest quantities of them. In studying the properties of such small amounts special methods have to be devised. As an instance of such a method which has been developed at the Bureau may be mentioned the

Emissivities of Metals and Oxides with Micropyrometer.

Metals		Cu	Ag	Au	Pd	Pt	Ir	Rh	Ni	Co	Fe	Mn	Ti
eλ = 0.65	solid	0.10	0.04	0.14	0.33	0.33	0.30	0.29	0.36	0.36	0.37	0.50	0.63
	liquid	.15	.07	.22	.37	.38	.....	.30	.37	.37	.37	.59	.65
eλ = 0.55	solid	.38	.35	.38	.38	.38	.....	.....	.44	.....	.....	.....	.75
	liquid	.36	.35	.38	.....	.....	.....	.....	.46	.....	.....	.....	.75

Metals		Zr	Th	Y	Er	Be	Cb	V	Cr	Mo	W	U	
eλ = 0.65	solid	0.32	0.36	0.35	0.55	0.61	0.49	0.35	0.39	0.43	0.39	0.54	.....
	liquid	.30	.40	.35	.38	.61	.40	.32	.39	.40	.....	.34	.....
eλ = 0.55	solid	.....	.36	.....	.....	.61	.61	.29	.53	.....	.....	.77	.....
	liquid	.....	.....	.....	.30	.81	.....	.....	.....	.....	.....	.....	.....

Oxides near F. P. s.		NiO	Co_3O_4	Fe_3O_4	Mn_3O_4	TiO_2	ThO_2	Y_2O_3	BeO	CbOx	V_2O_3	Cr_2O_3	U_3O_8
eλ = 0.65	solid	0.89	0.77	0.63	.....	0.52	0.57	0.61	0.37	0.71	0.69	0.60	0.30
	liquid	.68	.63	.53	0.47	.51	.69	.....	.....	.....	.....	.....	.31

[4] Burgess and Kellberg, "Electrical Resistance and Critical Ranges of Pure Iron," B. S. Scientific Paper No. 236, 1914.

micropyrometer,[5] with which the melting-points of many refractory metals, alloys, and oxides have been determined, as well as their specific radiation (emissivity) and its dependence upon temperature, using only a few milligrammes of the substance studied.[6] It is hoped to be able soon to publish the melting-points of all the refractory chemical elements.

Some of the results of emissivity and melting-points thus obtained with the micropyrometer, using less than 0.01 milligramme of the materials, are here tabulated.

Melting-points of Refractory Elements with Micropyrometer.

Mn	Co	Y	Cr	Fe	Zr	Cb	V
1260	1480	1490	1520 to > Fe	1530	(1600)	(1650)	1720

Ti	U	Rh	Th	Ir	Ru	Mo	Os
1800	(1850)	1960	(2350)	(2400)	(2450)	(2500)	(2650)

The values in parentheses are of considerable uncertainty on account of doubt as to purity or of difficulty of melting-point determination.

A considerable number of melting-points—particularly "fixed points" in thermometry and pyrometry—have been determined by other methods, notably by the use of the electrical resistance, thermo-electric, radiation, and optical pyrometers.[7] A study has also been made of the methods of thermal analysis.[8] Other methods have also been applied to the determination of the radiation characteristic of several substances, such as copper and its oxide[9] and the oxides of iron[10] and nickel.[11]

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[5] Burgess, "A Micropyrometer," B. S. Scientific Paper No. 198, 1912.

[6] Burgess and Waltenberg, "The Emissivity of Metals and Oxides: II. Measurements with the Micropyrometer," B. S. Scientific Paper No. 242, 1915.

[7] Waidner and Burgess, "Radiation and Melting-points of Pt and Pd," B. S. Scientific Paper No. 55, 1907; "Platinum Resistance Pyrometry at High Temperatures," B. S. Scientific Paper No. 124, 1909; "Note on the Temperature Scale Between 100 and 1500° C.," B. S. Scientific Paper No. 143, 1910.

[8] Burgess, "Methods of Obtaining Cooling Curves," B. S. Scientific Paper No. 99, 1908.

[9] Burgess, "Estimation of the Temperature of Copper by Means of Optical Pyrometers," B. S. Scientific Paper No. 121, 1909.

[10, 11] Burgess and Foote, "Emissivity of Metals and Oxides: I. Nickel Oxide," B. S. Scientific Paper No. 224, 1914; "IV. Iron Oxide," B. S. Scientific Paper No. 249, 1915.

QUALITY OF PLATINUM WARE.[12]

Another type of metal problem, in which the application of physical methods to the solution of a question of interest, this time primarily to chemists, and which came to us through a committee of the American Chemical Society, has been productive of interesting results; namely, that of the determination of the purity and quality of platinum ware, and especially of crucibles. An analysis which leaves the crucible intact and which also indicates the weight it loses on heating was the desideratum.

Applying well-known thermo-electric principles, it has been found to be easily possible to classify platinum of different degrees of purity, and by executing a series of heatings under exactly defined conditions at several temperatures the data necessary for the solution of the problem have been accumulated. Incidentally, from the examination of several hundred platinum utensils an idea of the quality of the platinum ware on the American market has been obtained, and the purchaser of platinum is now in a position to buy intelligently, using specifications which can be checked without injuring the articles purchased if he so chooses. The main experimental results of this investigation may be summarized briefly as follows:[13]

All platinum carries iron as impurity, which, diffusing to the surface and oxidizing on heating, tends to increase the crucible weight and mask the volatilization losses. These losses for platinum nearly free from iron, expressed in mg./100 cm.^{2}/hour at the temperatures indicated, are shown below:

Platinum containing	Pure Pt	1 per cent. Ir	2.5 per cent. Ir	8 per cent. Rh
900° C. or less	0	0	0	0
1000	0.08	0.3	0.57	0.07
1200	0.81	1.2	2.5	0.54

Platinum crucibles should be made, therefore, free from iron and iridium, and should contain a small percentage of rhodium. Further investigations may possibly demonstrate the superiority of platinum crucibles alloyed with osmium.

[12] Burgess and Sale, "A Study of the Quality of Platinum Ware," B. S. Scientific Paper No. 254, 1915.

[13] Burgess and Waltenberg, "Further Experiments on the Volatilization of Platinum," B. S. Scientific Paper in press.

COÖPERATIVE INVESTIGATIONS.

The Bureau of Standards carries on a large proportion of its researches in coöperation or after consultation with committees representing the several scientific or technical societies of the country interested in the particular subject. Oftentimes, as just noted in the case of platinum, a particular investigation is undertaken at the request of one or several societies or other representative technical body. The unfulfilled requests of this nature concerning metals alone would keep the whole Bureau staff busy for several years. This coöperation in laying out the work is a very excellent arrangement to both parties, the public and the Bureau, as it is evident that the Bureau gets a broader outlook upon any given problem than it could otherwise have, and it is certain, in its endeavors to solve the problems asked for, of the most hearty coöperation and advice of those most competent in the matter.

There is, for example, an Advisory Committee on Non-ferrous Alloys, composed of representatives of the several societies interested, which meets twice a year at the Bureau, and the frank interchange of ideas concerning the several problems has been most useful to all concerned. This is one of several such committees.

A problem thus handled is that of Standard Test Specimens of the Zinc Bronze 88 Cu–10 Sn–2 Zn, involving a systematic study of the variations of the different factors in foundry practice which might be expected to influence the quality and properties of the test specimen. This is accompanied, also, by investigation of the physical properties and their changes under varying conditions of production of the alloy. As a corollary has been carried out a study of the microstructure of this alloy which showed oxidation between crystals to be the most important source of detrimental effect on its properties,[14] as well as a study of structural changes accompanying heat treatment and mechanical work upon the alloy.[15] This may be said, therefore, to be a typical problem in physical metallurgy involving and correlating all the various factors mentioned at the outset of this paper, on a widely-used alloy commonly known as Government bronze.

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[14] Karr and Rawdon, "Standard Test Specimens of Zinc Bronze 88 Cu–10 Sn–2 Zn," B. S. Technologic Paper No. 59, 1916.

[15] Rawdon, "Microstructural Changes Accompanying the Annealing of Cast Bronze," B. S. Technologic Paper No. 60, 1916.

Many are the riddles in metals propounded to us by the several departments of the Federal Government and not a few, also, by state commissions and municipal bodies. As an illustration may be cited the investigation of tin fusible boiler plugs,[16] made at the instance of the Secretary of Commerce for the Steamboat-inspection Service. This is a device for preventing boiler explosion by the melting of a tin filling enclosed in a bronze casing screwed into the boiler between fire and water. Investigation showed, among other things, that plugs of impure tin, especially those containing zinc even as low as 0.3 per cent., will deteriorate, and the tin may finally all go over to oxide which melts at a temperature higher than the steel of the boiler, thus causing the plugs to become a source of danger, not of safety. In the course of this investigation over 1000 plugs—new and used—were examined and many interesting facts brought to light.

STUDY OF STRUCTURAL BRASSES.[17]

Many investigational problems have been taken up at the Bureau as the result of tests made for private firms or public service boards. Such tests oftentimes reveal hitherto unexplained characteristics of materials or sources of defects in them which seem to warrant much further investigation. An illustration is the study of the failure of structural brass by season-cracking or in similar manner. This work was taken up as a result of certain tests made for the New York Board of Water Supply of failed brass materials supplied them for use in the construction work of the Catskill aqueduct. These brasses, consisting mostly of so-called manganese bronze, of a total amount of approximately 3,000,000 pounds, were installed in the form of castings, forged and wrought bolts, ladders, etc., and to date an alarming percentage of failures has occurred among these materials.

It was early thought that the presence of internal, initial stresses in these materials might account for the failures which have occurred. Such stresses are introduced during the processes of manufacture, either during the cold working or as a result of unequal cooling of different parts of an article, and are generally,

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[16] Burgess and Merica, "Investigation of Fusible Tin Boiler Plugs," B. S. Technologic Paper No. 53, 1915.

[17] Merica and Woodward, preliminary publication, *Proc. Am. Inst. of Metals,* 1915.

but not always, found as a result of attempts to obtain undue hardness in the brass.

To date some 250 samples of the type of brass in question have been investigated in the attempt to correlate failures with the presence of these internal stresses, and these, in turn, with the physical properties, such that engineers may have some data upon which to formulate in the future their specifications for such materials in order to avoid the danger of the repetition of this type of failure on such a large scale.

Several subsidiary investigations on brass have also arisen, such as the stresses developed in castings on welding or "burning-in," and the effect on the properties of the material of the presence of minute quantities of certain impurities, as cadmium.

Another very practical problem being studied at the Bureau is the question of the properties and quality of electro-deposited copper in connection with electrotyping and similar work. Studies are being made of the mechanical properties as affected by the conditions of deposition, etc., and in correlation with the study of the micro-structure.

COOPERATION WITH MANUFACTURERS.

The Bureau has been particularly fortunate in having had placed at its disposal without restriction the facilities of manufacturing plants, such as of brass and steel manufacturing companies, for the carrying out of investigations, the execution of which would have been otherwise impossible except at enormous and practically prohibitive expense. This has made possible, for example, the investigation of finishing temperatures and properties of rails,[18] a problem not yet completely solved and in which many other factors are involved, and one which gave us the opportunity of demonstrating the practicability of pyrometric control of rolling-mill operations.

Another investigation in which there could have been no considerable advance without hearty coöperation on the part of steel manufacturers is the sound ingot research, about which there has been some preliminary publication,[19] which is still in progress.

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[18] Burgess, Crowe, Rawdon, and Waltenberg, "Finishing Temperatures and Properties of Rails," B. S. Technologic Paper No. 38, 1913.

[19] Hadfield and Burgess, "Sound Ingots and Rails," *Am. Inst. of Mining Engrs., Feb.*, 1915. *Journ. Iron and Steel Inst.*, May, 1915.

The same is, of course, true of the investigation under way to determine the best type of "test ingot" to use in sampling steel for analysis, an investigation in coöperation with the American Society of Testing Materials.

Another problem may also be mentioned which is nearing solution and for which we have used several steel plants as laboratories; namely, the pyrometric control of steel furnace and pouring operations. The results thus far obtained indicate the possibility of exact measurement of temperatures of pouring steel and a reasonably precise control of the open-hearth furnace operations.

Here it seems appropriate to refer at least to a feature of our work which we highly prize, and one which is to us most valuable; namely, the fact that work done at the Bureau, because of its public origin, very often incites discussion, both oral and written, which may be of greater value than the main plan itself, and brings thus to light facts and experience that might otherwise pass unnoticed. Our experience has in this respect been most happy, and many manufacturers, for instance, with whom we have had the pleasure of dealing have had a most generous array of practical experience to offer in comment on certain phases of work in which the interest has been common.

METAL FAILURES.

The Bureau, as indicated above, does a great deal of investigation of failed material, and some of the cases studied present varied points of interest, and also illustrate the present-day method of metal and metallurgical investigation. A word about the failure of metals in general may, therefore, not be out of place.

The question of metal failures is a very comprehensive one and, indeed, may be said to embrace all cases in which a metal does not fulfil as well as may be the use or uses to which it is put Whether or not a metal is a failure under given conditions may, therefore, be a relative matter, and there cannot usually be an ideal standard of service—for example, *all* steel rails eventually wear out, and so, in a sense, all such rails finally fail to perform the duty imposed upon them, but a rail lasting several years or months, as the case may be, is apparently to be classed as a sound rail as compared with one in which a flaw develops soon after laying in the track. The rail which has stood up well may, nevertheless, not be a sound one. It may possess a hidden defect, originating in the

ingot from which it was rolled, and which may eventually bring about a sudden collapse causing accident. Or, again, the changes in the conditions of train service in the track, such as heavier locomotives or its upkeep, may have occurred, resulting in a rail failure due to too severe service conditions or insufficient care of the road-bed or ties.

Of metals we may say then, as of men, some are born failures, some acquire failure, and others have failure thrust upon them. Fortunately for the metals, some cases, but not all, of "born failures" may be cured, either by amputation or treatment, if the subject is taken in hand early enough in its career.

Metal failures may evidently be classified as to type or cause, whether due to inherent chemical or physical imperfections or to some incorrect treatment, as thermal, mechanical, or chemical, which it may have received either in manufacture or subsequently.

Several well-known methods of detecting failures and studying failed metals have been developed. It is often necessary, also, in studying metal failures, to fix the responsibility, and it may be necessary at times to decide whether the fault is in the metal or in the specifications, which may have been so incorrectly or inadequately drawn as to be entirely unsuited for the metal in question—the metal has had failure thrust upon it. This happens more frequently than is perhaps generally appreciated, and a very notorious example of this has occurred in the search for a non-corrodible metal as strong as steel—with the result that manganese bronze in engineering construction may be said at present to be on the blacklist.

The question of tolerances in chemical composition—for instance of many types of steel and of certain non-ferrous alloys—is oftentimes a puzzling one and introduces complications in the endeavor to apportion blame for the failure; and the acceptance or rejection of alloys of stated and complex composition on chemical analysis—the legitimate prevention of failure in those cases for which the relation of composition to performance is really known, which it seldom is adequately—is oftentimes shrouded in mystery and encircled with doubt. There is a great deal of uncertain knowledge—or certain ignorance, as you will—all about this aspect of chemical composition and its relation to the subject of metal failures and their prevention.

For example, let us look at the supposed chemical safeguards

thrown about the acceptance of steel rails in various countries avowedly with a view to prevention of their failure. The United States and Great Britain, of which metallurgically we may be said to be a colony, specify narrow or maximum limits for the elements carbon, manganese, phosphorus, silicon, and sulphur; and yet statistics show, I believe, relatively the most rail failures in the United States and nearly, if not quite, the least in Great Britain. Therefore, one might argue, as do the German and French apparently, the chemical analysis means nothing as to ultimate behavior of the rails. The question of dual requirements, both chemical and physical, in specifications is always with us, and I do not mean to more than call your attention to it in this discussion of failures. There is one aspect of the rôle of chemical specifications, however, which is evidently of importance; namely, where there is an abrupt change of phase accompanied by marked change in physical properties, as is the case for certain bronzes and brasses as well as steel, it is evidently desirable or necessary to so limit the composition that the alloy will normally be of the desired composition and hence of the properties expected.

For certain uses one or another of the pure metals as distinguished from an alloy has been found desirable. The question then arises: What degree of purity should be insisted upon to avoid failure, and what impurities may be allowed, if any? For each case the answer to this question can be found only by careful investigation and trials in service.

There is one type of failure to which most metals, and particularly metallic alloys, are subject in high or low degree and which is probably the most deadly disease of the metal realm—I mean corrosion—the examples of which would be infinite. Many and varied are the methods employed to ward off this fatal malady, some aspects of which have been studied at the Bureau, but their discussion would take us far afield.

Finally, the analogy of metal failures to diseases is made most complete by the existence of what we may call imaginary ills, such as the supposed metastabilities and allotropies of some of the more common metals, including zinc, lead, and copper—or, in the words of Rosenhain, "allotropy gone mad." Thus for copper has been assigned a phase change at about 70° C. An examination of this metal, however, by the electrical resistance method has convinced us that to at least 1 in 50,000 there is no evidence of

allotropy and consequent metastability in copper between 0° and 100°.[20]

The question which, of course, goes hand in hand with that of metal failures is: their prevention—how may it be accomplished? In many cases the answer is indicated immediately with the determination of the cause of failure. In many others the answer is not at hand with our present knowledge, so that this field of science, as all others, is a prolific one for further research.

With this incomplete statement regarding some general aspects of the question of metal failures, let us now consider some specific examples, taken for the most part from our experience at the Bureau of Standards.

(Several cases illustrated by lantern slides.)

RAILWAY MATERIALS.

A group of materials of which the failure in service is particularly serious is that of railway materials, such as rails, wheels, axles, tires, etc. An investigation of some of the causes of failure in such materials has been started at the Bureau. (A few typical examples of rail failures investigated at the Bureau, including a "flowed rail," piped rails, and transverse fissures were shown in the slides.) A great many of such failures are to be traced directly to the ingot, as was indicated above.

In its study of this subject the Bureau is having the cordial co-operation of the railroads and manufacturers of such material. Several methods of attack are being used, including a comparison of foreign specifications for railroad materials and resulting service as expressed in accident statistics;[21] a survey of the experience of American railroads regarding certain types of failure, as transverse fissures in rails, the behavior, design, service, and typical failures of the several types of car wheel; and these statistical studies are, of course, being supplemented by extended experimental researches now under way, some of which are mentioned above, including sound ingots, the causes of transverse fissures, cracking of car wheels due to braking, and several others.

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[20] Burgess and Kellberg, "On a Supposed Allotropy of Copper," *Jour. Wash. Acad.*, **5**, p. 657, 1915.

[21] Burgess and Merica, "Some Foreign Railway Specifications: Wheels, Rails, Axles, Tires," B. S. Technologic Paper No. 61, 1916.

CONCLUSION.

As is evident from the foregoing, our program in physical metallurgy is a rather ambitious one and the criticism may perhaps be offered, as it has been already, that it is too extensive for the forces, both physical and vital, at our disposal. It may, however, be replied, obviously, that it is not without the bounds of possibility to increase these forces, a condition much to be desired so that Physical Metallurgy may be helped thereby to take a place worthy of its importance in the community and commensurate with the vast metal industries of our country; again, that a considerable number of the important problems now being attacked will eventually be solved along the lines laid down and within a reasonable time may be assured if one notes from Table I the record of publications describing the progress hitherto made in the investigation of metals at the Bureau of Standards.

The Relation Between Contact Potentials and Electrochemical Action. T. LANGMUIR. (*Proceedings of the American Electrochemical Society*, April 29, 1916.)—The history of electrochemistry has been marked by a century-long conflict between the contact theory and the chemical theory of electrochemical action. The modern electrochemist usually considers that this conflict has long been brought to a close by the victory of the chemical theory. He believes that contact potentials between metals are entirely inappreciable. No such uniformity of opinion has existed among physicists. Within the last few years very remarkable work in physics has demonstrated that contact potentials of large magnitude do exist, even between pure metals in a practically perfect vacuum. This evidence, which is reviewed in some detail, has been obtained by a study of (1) electron emission from heated metals; (2) photoelectric phenomena; (3) contact potentials. Several independent methods lead to values of contact potentials which are in substantial agreement.

Much of the difficulty which the electrochemist has had in reconciling the contact theory with the known intimate relation between chemical action and electrochemical phenomena has been due to failure to properly define "potential difference" and "electromotive force." Definitions of these are given and a theory of the mechanism of the effect is developed. It is not necessary to take into account contact potentials when only the electromotive forces of reversible cells are considered. But in dealing with the kinetic phenomena, such as overvoltage and passivity, or with effects due to single potential differences, the contact potential must be an essential factor.

Activity of American Shipyards. J. G. DONANCE. (*Scientific American,* vol. cxiv, No. 22, May 27, 1916.)—Not since the palmy days of the Yankee clipper has there been given to our shipbuilding and shipping, but most of all the former, so real an impetus as they have both received within a few months' time. In 1914 these industries had reached their low ebb here, and it was then that chance interfered to offer American initiative the opportunity to make a change. Vessels of foreign make were beginning to have their registry changed under the act of August 18, 1914, so that some few American shippers began to see their chances, and took them, as did some others who were not either shipowners or shipbuilders, but decided to become so. Their judgment has since been amply justified.

On July 1, 1915, there were building or under contract in American shipyards 46 vessels: between that time and December 1, 52 additional ships were ordered, bringing the total of those under construction up to 761,511 gross tons on the latter date. Of them, 47 were built to hold bulk oil, 34 general freight, 11 were colliers, and 6 for passengers and freight. These figures are a good index as to the character of the present trade.

Deducting vessels lost, abandoned, or sold to aliens up to December 1, there is a net increase of 187 vessels, 53,829 gross tons, in our merchant marine since the 1st of last July. There is now under construction at just four of the leading yards a gross tonnage amounting to 413,000, as contrasted with a total of 316,000 tons for ships built during the year of 1914 and 346,000 for those of 1913. Vessels arriving last year at the port of New York were 10,279 in number, and 9203 the year before. Prices of American-built vessels have advanced 50 per cent. in six months, and labor has enjoyed a corresponding increase. Some of the greatest shipbuilding nations of the world, formerly, are now no longer able to hold their own along commercial building lines. Other countries are stepping into their places. But yet the world production of ships is far below the normal, and manufacturers here are trying hard to make this up.

THE ELEMENT OF CHANCE IN SANITATION.*

BY

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CHANCE is an element with which we have to deal in sanitation just as we have to consider it in studying natural phenomena. This does not mean that events happen without cause, but that there are so many causes of the events that we cannot consider each alone. Given a certain number of causes, these may combine in many ways to produce many events, some of which happen often and some rarely. The frequency with which given events will happen is subject to mathematical analysis according to the theories of probability. We sometimes speak of these as the laws of chance.

Consciously or unconsciously we are making use of these laws of chance in everyday life. Generally we use them in a crude and unscientific way. The business man considers the possibility of certain events happening and adjusts the selling price of his goods accordingly. The stock broker does this on a more elaborate scale. Carried to the limit, his operations become speculation. The whole business of insurance is founded upon the idea of chance. For example, in life insurance, regular annual receipts from the policy-holder are put against the payment of a lump sum at the time of death, and the probability of the number of such annual payments being received before death is used as the basis of determining the rate of insurance.[1] Indeed, in early days, life insurance was regarded as a sort of gambling and at one time was prohibited by law, the risks being considered to be all on one side. Nowadays it is understood that by the proper use of the laws of chance it is possible to make fair adjustments between the insurers and the insured. What really happens is that those who live long pay to the families of the insured who die young, or, as one might say, the strong help the weak, the insurance companies acting as adjusters and, of course, taking a certain part payment for their

* Presented at the meeting of the Mechanical and Engineering Section held Thursday, March 9, 1916.

[1] More strictly, it is the probability of living from one year to another.

services. So it is in fire insurance: those whose insured buildings do not burn pay to those who lose by fire.

The measurement of errors of observations in all kinds of scientific work shows that the small errors occur frequently and that the large errors occur less frequently. The relation between the frequency of occurrence of large and small errors has become known as the "law of error." It is practically the same as the law of variation in natural phenomena. If one measures the heights of a thousand men or the lengths of a hundred oak leaves or the weights of a dozen apples, it will be found that the items when arranged in order of magnitude follow this general law of frequency, and so rigid appears to be the application of the law that, knowing the variations in the heights of a thousand men, it is possible to calculate the frequency with which one may expect to find a dwarf or a giant.

The laws of chance are well known to the gambler, although not expressed by him in algebraic form. It is interesting to remember that some of the first mathematical studies of probability were made for the benefit of gamesters. The frequency with which certain combinations of dice or cards may be thrown has been found to be susceptible of mathematical demonstration, and the mathematical laws deduced from theory have been proved by experiment. The roulette wheel is scientifically planned, and even in the penny-in-the-slot machine, with its pegs and pockets arranged like a bagetelle board, there is a striking similarity between the values of the prizes offered for putting the penny into the different pockets and the normal curve of error. The engineer unconsciously uses the laws of chance when he allows a factor of safety in designing a bridge, recognizing that there is a certain possible chance of unsuspected loading of the span or some unsuspected weakness in the steel. Recently it has been found that annual rainfall records in a given locality follow the general law, so that from a series of records covering only twenty years it is possible to predict the probable maximum or minimum rainfall in a period of 50, 100, or 150 years. This is useful in designing the spillways of dams, and in determining the capacities of sewers. Many other natural phenomena may similarly be shown to be subject to these laws.

Although the laws of chance were developed many years ago by mathematicians and students of the exact sciences, it is in the

realm of biology that the most important applications have been most recently made. Only within a comparatively few years have engineers realized the practical value of these laws outside of the adjustment of errors of observation. The books on Least Squares, which deal with the subject of chance and balanced errors, have been written chiefly from the standpoint of the precision of measurement. This is natural, for the engineering sciences are to a great extent exact sciences, while biology deals with plants and animals which group themselves in various ways, and which possess many varying characteristics. In biology, therefore, the study of variation is all-important. Sanitary engineering is a science which in some ways occupies an intermediate place between the natural sciences and the exact sciences. It deals not only with mathematics and physics, but with chemistry and biology. There are many ways, therefore, in which the laws of frequency may be found useful in sanitation. The purpose of this address is not to formulate these laws in a definite manner, but merely to point out some ways in which they may be used and how a knowledge of the general idea of variation will help to control our use of certain measurements and tests in common use. It is the hope of the author that these studies may stimulate many detailed investigations along similar lines.

The Idea of Variation.—When many different measurements of a certain quantity have been made, it is common to generalize them by computing the average; that is, the numerical mean. This is a simple and useful method, but it often fails to give a complete picture of the individual measurements in the series. In fact, two groups of items of very different magnitude may yield the same average. For example, the average of each of the following series is the same; namely, 7:

	6		1
	7		2
	6		1
	9		3
	7		28
Average.........	7	Average.........	7

Although having the same average, the figures in the two groups are very different. Evidently in this case the average does not give a satisfactory generalization.

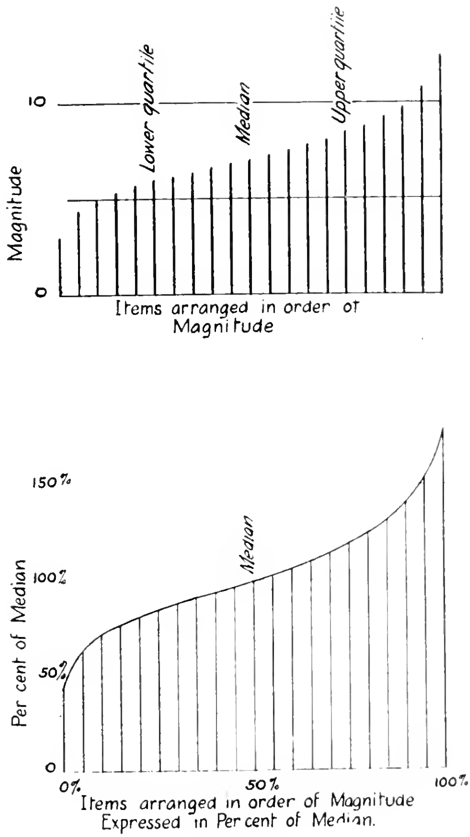
It is possible to study the items of a series in other ways than by computing the arithmetical mean. Let us take the simple case of 21 items, arranged in order of magnitude:

	3.0
	4.4
	5.0
	5.4
	5.7
	6.0
	6.2
	6.4
	6.6
	6.8
	7.0
	7.3
	7.5
	7.8
	8.1
	8.5
	8.8
	9.3
	9.8
	10.8
	12.5
Average..............	7.28

The item that is in the middle of the series when thus arranged is called the median. In this case the median is 7. It is not necessarily the same as the mean, which in this case is 7.28. In the previous comparison of the two dissimilar groups of five items the median of the first group was 7, which was the same as the mean, but the median of the second group was 2, which was much lower than the mean. A comparison of the mean and the median gives a better picture of the groups than either alone. When the items of a series are quite uniform, the mean and the median are nearly alike; but when the mean is much greater than the median, it indicates that the group includes items abnormally high, and when the mean is much less than the median, it indicates that the group includes some items abnormally low. Obviously there is an equal chance of any items being above or below the median, the median being by definition the middle term of the series when the items are arranged in order of magnitude. The labor of arranging a

series of observations in order of magnitude and finding the middle term is not as great as might at first be thought. In case there is an even number of terms, the median may be taken as the average of the middle two terms. This may not be its most probable value when great accuracy is needed, but it is usually near enough for all practical purposes.

FIG. 1.



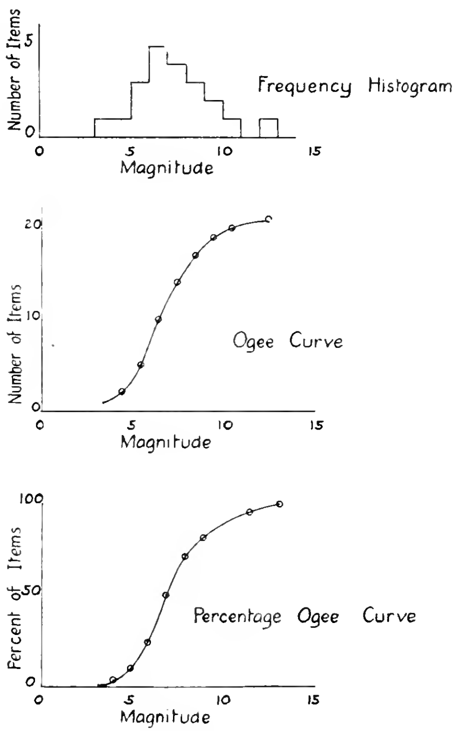
Curve of variation.

The series may be further described by finding values of the terms which lie half way between the median and the ends of the series; that is, one-quarter way from one end of the series to the other. These are called the upper quartile and the lower quartile, and in the series mentioned have the values of 6 and 8.5 respec-

tively. In the same way we might find the value of the term which lies one-tenth of the way from one end of the series, the decentile, and so on. Taken together these are sometimes called the "percentile grades," a term used by Sir Francis Galton.

In Fig. 1 these items are placed in array first in order of magnitude, and second in order of magnitude expressed in terms of percentage of the median. If desired, a horizontal scale may be

FIG. 2.



Frequency curves.

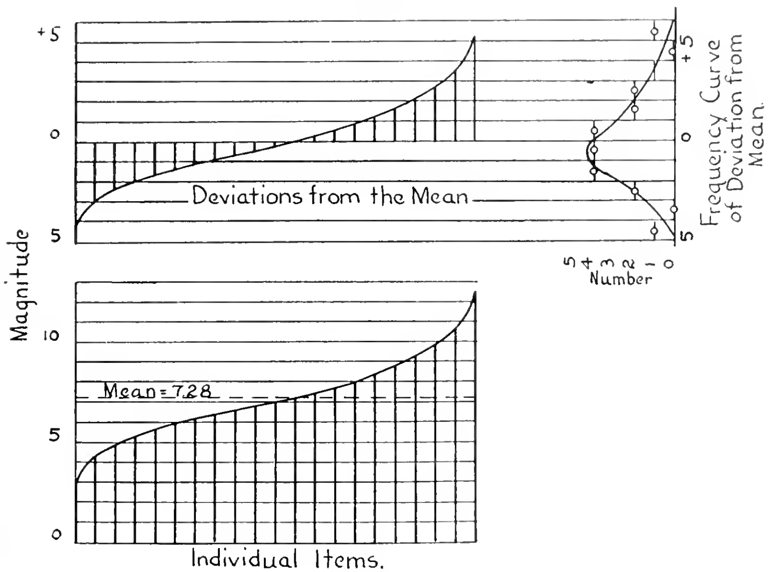
used, the total number of observations being taken as 100 per cent. and the median being, of course, 50 per cent.

Frequency.—Where there is a large number of items in the series the labor of considering them all in array becomes so great that it is easier and better to combine them into groups. When this is done and the results plotted with the magnitudes of the items as abscissæ and the numbers of items in each magnitude group as ordinates, the result is called a frequency curve. This

"frequency polygon" or "frequency histogram" plays a very important part in statistical investigations.

If the numbers in the above-mentioned series are combined into groups and plotted in this way, it will be noticed that there is a certain magnitude which is more common than any other (Fig. 2). Five of the items fall into group 6–7, and the peak of the frequency curve is seen to occur at a magnitude of 6.5. This value is called the *mode*, as it is the one which should be found more often than any other.

FIG. 3.



Frequency curves.

Other methods of showing frequency are illustrated in Fig. 2; namely, the ogee curves. Here the ordinates indicate the number of items which are less in magnitude than the abscissæ.

Dispersion.—Again, we may study our series of items by ascertaining how the individual results vary from the mean value. Plotting them as in Fig. 3, it is seen that the curve is the same as the curve of variation. It will be found that most of the items are relatively close to the mean, but that a few are farther from it, and a still smaller number farther yet. This is shown by the frequency curve of the deviation from the mean. For convenience of discussion these deviations from the mean may be called

"errors." The most probable error is that deviation from the mean which is just as likely to be exceeded as not. It might be termed the "median error." According to Least Squares, the value of the probable error (r) of a set of observations is $0.6745 \sqrt{\frac{\Sigma x^2}{n}}$, in which x is any individual error, n the number of observations, and 0.6745 a numerical constant. The expression $\sqrt{\frac{\Sigma x^2}{n}}$ is called the "standard deviation from the mean, or the mean error." In the series given above the mean error is 2.15 and the probable error (r) is 1.45.

Determination of Probable Error.

Item	Deviation from mean x	Square of deviation x^2
3.0	−4.28	18.32
4.4	−2.84	8.07
5.0	−2.28	5.20
5.4	−1.88	3.53
5.7	−1.58	2.50
6.0	−1.28	1.64
6.2	−1.08	1.17
6.4	−0.88	.77
6.6	−0.68	.46
6.8	−0.48	.23
7.0	−0.28	.08
7.3	+0.02	.0004
7.5	+0.22	.05
7.8	+ .52	.27
8.1	+ .82	.67
8.5	+1.22	1.49
8.8	+1.52	2.31
9.3	+2.02	4.08
9.8	+2.52	6.35
10.8	+3.52	12.39
12.5	+5.22	27.25
Mean = 7.28		Sum = 96.83

$$96.83 \div 21 = 4.61 = \frac{\Sigma x^2}{n}.$$

$\sqrt{4.61} = 2.15 =$ standard deviation.

$2.15 \times .6745 = 1.45 =$ probable error (r).

$1.45 \div 7.28 = .199 =$ coefficient of variation.

Maximum error $= 12.5 - 7.28 = 5.22''$

$5.22 \div 1.45 = 3.5 =$ maximum value of $\frac{x}{r}$.

It should be noted that some of the errors are positive and some negative, but that in computing the mean error the sign is disregarded; for all of the values of x^2 are positive. In computing the value of the probable error the frequency curve of deviation is supposed to be symmetrical.

TABLE I.

Probability of the Occurrence of Errors.

r = the probable error = 0.6745m.

m = the mean error = 1.4826r = $\sqrt{\frac{\Sigma x^2}{n}}$.

x = an individual error.
n = number of observations.

$\frac{x}{r}$	0	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0054	0.0108	0.0161	0.0215	0.0269	0.0323	0.0377	0.0430	0.0484
0.1	0538	0591	0645	0699	0752	0806	0859	0913	0966	1020
0.2	1073	1126	1180	1233	1286	1339	1392	1445	1498	1551
0.3	1603	1656	1709	1761	1814	1866	1918	1971	2023	2075
0.4	2127	2179	2230	2282	2334	2385	2436	2488	2539	2590
0.5	0.2641	0.2691	0.2742	0.2793	0.2843	0.2893	0.2944	0.2994	0.3043	0.3093
0.6	3143	3192	3242	3291	3340	3389	3438	3487	3535	3583
0.7	3632	3680	3728	3775	3823	3870	3918	3965	4012	4059
0.8	4105	4152	4198	4244	4290	4336	4381	4427	4472	4517
0.9	4562	4606	4651	4695	4739	4783	4827	4860	4914	4957
1.0	0.5000	0.5043	0.5085	0.5128	0.5170	0.5212	0.5254	0.5295	0.5337	0.5378
1.1	5419	5460	5500	5540	5581	5620	5660	5700	5739	5778
1.2	5817	5856	5894	5932	5970	6008	6046	6083	6120	6157
1.3	6194	6231	6267	6303	6339	6375	6410	6445	6480	6515
1.4	6550	6584	6618	6652	6686	6719	6753	6786	6818	6851
1.5	0.6883	0.6915	0.6947	0.6979	0.7011	0.7042	0.7073	0.7104	0.7134	0.7165
1.6	7195	7225	7255	7284	7313	7342	7371	7400	7428	7457
1.7	7485	7512	7540	7567	7594	7621	7648	7675	7701	7727
1.8	7753	7778	7804	7829	7854	7879	7904	7928	7952	7976
1.9	8000	8023	8047	8070	8093	8116	8138	8161	8183	8205
2.0	0.8227	0.8248	0.8270	0.8291	0.8312	0.8332	0.8353	0.8373	0.8394	0.8414
2.1	8433	8453	8473	8492	8511	8530	8549	8567	8585	8604
2.2	8622	8639	8657	8674	8692	8709	8726	8742	8759	8775
2.3	8792	8808	8824	8840	8855	8870	8886	8901	8916	8930
2.4	8945	8960	8974	8988	9002	9016	9029	9043	9056	9069
2.5	0.9082	0.9095	0.9108	0.9121	0.9133	0.9146	0.9158	0.9170	0.9182	0.9193
2.6	9205	9217	9228	9239	9250	9261	9272	9283	9293	9304
2.7	9314	9324	9334	9344	9354	9364	9373	9383	9392	9401
2.8	9410	9419	9428	9437	9446	9454	9463	9471	9479	9487
2.9	9495	9503	9511	9519	9526	9534	9541	9548	9556	9563
3.0	0.9570	0.9577	0.9583	0.9590	0.9597	0.9603	0.9610	0.9616	0.9622	0.9629
3.1	9635	9641	9647	9652	9658	9664	9669	9675	9680	9686
3.2	9691	9696	9701	9706	9711	9716	9721	9726	9731	9735
3.3	9740	9744	9749	9753	9757	9761	9766	9770	9774	9778
3.4	9782	9786	9789	9793	9797	9800	9804	9807	9811	9814

3	0.9570	0.9635	0.9691	0.9740	0.9782	0.9818	0.9848	0.9874	0.9896	0.9915
4	9930	9943	9954	9963	9970	9976	9981	9985	9988	9990
5	9993	9994	9996	9997	9997	9998	9998	9999	9999	9999
0	1.0000									

Without going into detail, it may be said that it is possible to compute the frequency with which errors of a given magnitude are found. By definition the probable error is just as likely as not to occur. Its chance of occurring is 1 : 1; that is, 1 in 2. This

probability is generally stated as ½, or 0.50, or 50 per cent. The chance of any deviation being less than certain amounts is shown in Table I, taken from Merriman's book on Least Squares. In the first column of this table the fraction $\frac{x}{r}$ represents the magnitude of an individual deviation from the mean compared to the probable error. For example, if $\frac{x}{r} = 1$, the deviation from the mean is the same as the probable error; and the chances are even that x will occur. The probability is therefore stated as 50 per cent., or 0.500, as given in the second column. The probability that a deviation of less than one-half of the probable error will occur is 0.2641, and that an error less than twice the probable error will occur is 0.8227. The sum of the chances that a deviation will or will not occur is, of course, unity. Probabilities of the occurrence of errors less than other relative magnitudes, as compared with the most probable error, can be picked out from the various columns of this table. Probabilities of the occurrence of "greater errors" can be obtained by subtracting the figures in the table from 1.

The values of $\frac{x}{r}$ for different probabilities, according to Merriman and Jones, are given in Table II.

In Jones's Tables, page 160, will be found another probability table. Unlike Merriman's, this is based on half, not on all of the variation curve, and the figures for probability indicate the probability that the given value of $\frac{x}{r}$ will be exceeded.

Thus, Merriman's probability value of 0.80 indicates that 80 per cent. of all the observations will be less than $\frac{x}{r} = 1.90$. Therefore $1 - 0.80$, or 0.20, of the observations will be greater than 1.90. Of these, 0.10 will be at one end of the curve and 0.10 at the other end. Hence we find 1.90 opposite 0.10 in Jones's table.

Probability Paper.—The values of the probability of the occurrence of the different values of $\frac{x}{r}$ (based on Jones's figures for half the frequency curve) are shown in Fig. 4. This is a graphical representation of the law of error, on one side of the median. For obvious reasons it is not convenient to use.

TABLE II.

Probabilities of the Occurrence of Certain Values of $\frac{x}{r}$

A Ratio of given error (x) to the probable error (r) $\left(\frac{x}{r}\right)$.	B Probability of the deviation being less than this value (including all observations regardless of sign).	C Probability of the deviation being greater than this value (including only half of the observation, *i.e.*, of the same sign).
.02	.01	.495
.04	.02	.490
.06	.03	.485
.09	.05	.475
.19	.10	.450
.38	.20	.400
.58	.30	.350
.77	.40	.300
1.00	.50	.250
1.25	.60	.200
1.54	.70	.150
1.90	.80	.100
2.438	.90	.050
3.045	.96	.020
3.449	.98	.010
3.821	.99	.005
4.267	.996	.002
4.587	.998	.001
4.887	.999	.0005
5.250	.9996	.0002
5.525	.9998	.0001
5.783	.9999	.00005
6.090	.99996	.00002
6.332	.99998	.00001
6.592	.99999	.000005
6.853	.999996	.000002
7.063	.999998	.000001
7.258	.999999	.0000005
7.548	.9999996	.0000002
7.758	.9999998	.0000001
7.967	.9999999	.00000005

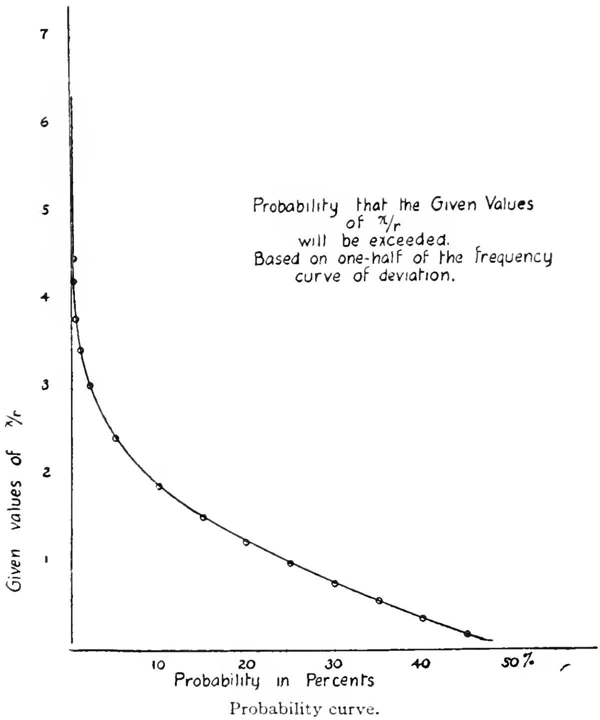
B. From Merriman's "Least Squares," page 221.
C. From Jones's Tables, page 160.

It occurred to my partner, Allen Hazen, in 1914, that a paper might be ruled with the horizontal scale so divided that this curve of probability would plot as a straight line. And hence any series of observations which varied in accordance with this probability

would also plot as a straight line, for the same reason that the curve of deviation and the curve of variation are coincident. This paper was first used in a study of the storage to be provided in impounding reservoirs for municipal water supplies.[2]

In making this paper, the central point on the horizontal scale was marked 50 and represents the median observation; that is, the item which has a probability of 0.50. The other points on the scale are laid off in either direction from this central point, so that

FIG. 4.



Probability curve.

40 and 60, 30 and 70, 1 and 99, 0.01 and 99.99, etc., are equidistant from the centre. In other words, the frequency curve is assumed to be symmetrical.

The distances from the centre are laid out by plotting the values of $\frac{x}{r}$ for corresponding values of probability as given in Jones's table. Thus 0.01 is 5.525 divisions on the scale from the centre,

[2] Allen Hazen, *Trans. Am. Soc. C. E.*, lxxvii, p. 1539.

0.1 is 4.587 divisions from the centre, etc., as shown on the attached sheet.

The figures used by Hazen in laying out the diagram were substantially those given above. Hazen gives them as shown in Table III.

TABLE III.

Relative Distances of Lines on Probability Paper from Central or 50 Per Cent. Line.

(This covers one-half of sheet. The other half is reversed.)

Line, Per cent.	Relative distance	Line, Per cent.	Relative distance
50	0.000	8	2.083
48	0.074	7	2.188
46	0.149	6	2.305
44	0.224	5	2.439
42	0.300	4	2.596
40	0.376	3	2.789
38	0.453	2	3.045
36	0.531	1	3.450
34	0.611	0.9	3.507
32	0.693	0.8	3.573
30	0.777	0.7	3.646
28	0.864	0.6	3.727
26	0.954	0.5	3.821
24	1.047	0.4	3.933
22	1.145	0.3	4.077
20	1.248	0.2	4.267
19	1.302	0.1	4.585
18	1.357	0.09	4.630
17	1.415	0.08	4.685
16	1.474	0.07	4.748
15	1.537	0.06	4.817
14	1.602	0.05	4.900
13	1.670	0.04	5.000
12	1.742	0.03	5.120
11	1.818	0.02	5.290
10	1.900	0.01	5.550
9	1.988	0	

With the diagram thus laid out, the values of $\frac{x}{r}$ plotted on the probability scale will fall on a straight line. And, conversely, if the items of a series of observations plotted on this paper fall on a straight line, it indicates that they form a probability series; that is, they occur according to the laws of chance.

Hazen's paper is intended for symmetrical frequency curves; but not all frequency curves are symmetrical. Such writers as Karl Pearson and his school of biometricians have described various types of frequency curves. These have not been included in the present study, but there seems to be no reason why they, too, may not be simplified and made more useful by methods similar to Hazen's.

In any series of observations some items are liable to be so far from the mean as to be of doubtful value. These should be rejected. Merriman has given the values of the observations which should be rejected in any series as follows. Naturally the ratio of $\frac{x}{r}$ increases according to the number of observations in the series:

Number of observations in the series	$\frac{x}{r}$	Number of observations in the series	$\frac{x}{r}$
3	2.05	18	3.26
4	2.27	19	3.29
5	2.44	20	3.32
6	2.57	21	3.35
7	2.67	22	3.38
8	2.76	23	3.41
9	2.84	24	3.43
10	2.91	25	3.45
11	2.96	30	3.55
12	3.02	40	3.70
13	3.07	50	3.82
14	3.12	75	4.02
15	3.16	100	4.16
16	3.19	200	4.48
17	3.22	500	4.90

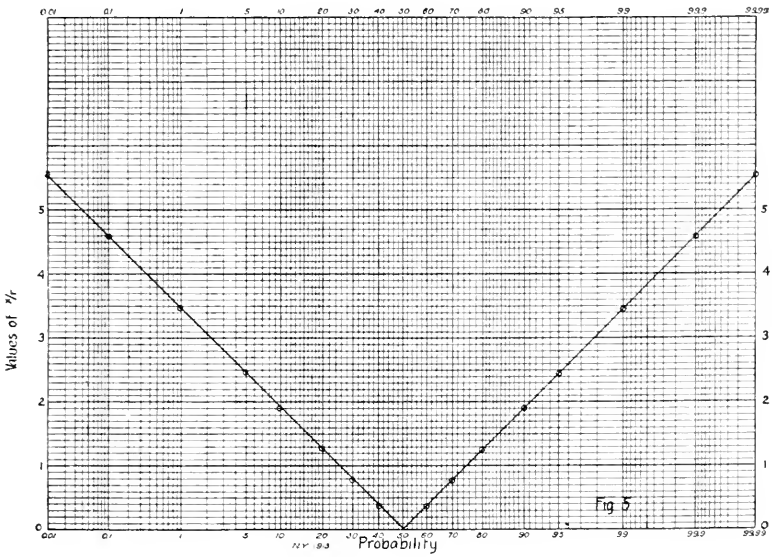
In the series of 21 items given above, the last item has a value of 12.5. The value of $\frac{x}{r}$ is 3.5. According to Merriman, this item should be excluded from the series.

If, in a series of daily observations of the number of bacteria in a filter effluent extending over a year the deviation of any determination from the mean should be found to be more than five times as much as the probable error, to use a round number, this should be rejected from the series as being, for some reason or other, abnormal. This principle is likely to play an important part in future discussions of this subject.

Use of Arithmetic-probability Paper.—On arithmetic-probability paper the normal curve of error plots out as a straight line on either side of the median point. This follows from construction, but it is illustrated by Fig. 5, in which the ordinates represent values of $\frac{x}{r}$ and the abscissæ probability expressed in percentage.

It is interesting to notice also that the coefficients of the different terms of a binomial series of the form $(1+1)^n$ plot out on this paper as a straight line. This also follows directly from

FIG. 5.



Law of probability plotted on probability paper.

the laws of chance. A discussion of this relation may be found in works on the theory of statistics (Fig. 6).

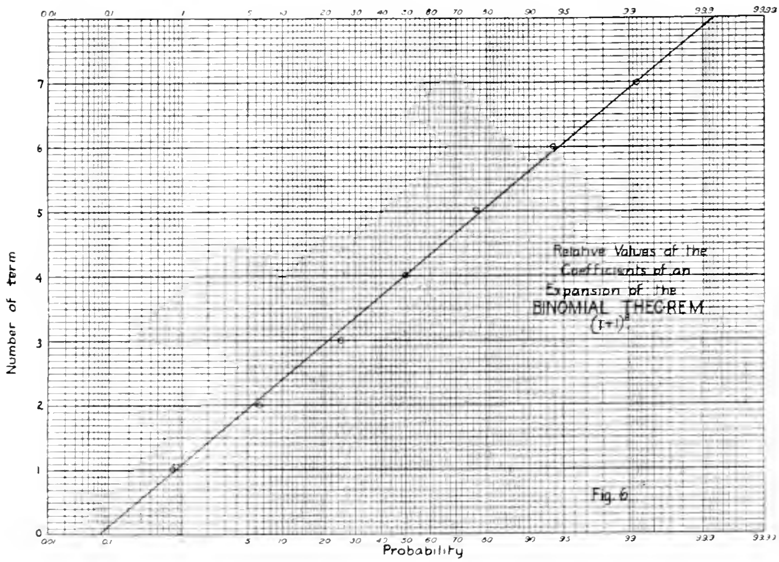
Fig. 7 shows the results obtained in chance by tossing 14 coins 150 times according to the table in Elderton's "Primer of Statistics." In this case the ordinates represent the number of heads which appeared. It will be noticed that the median was about 7. If there had been an indefinite number of throws, instead of 150 throws, the median would, of course, have been exactly 7; that is, heads would have been thrown half of the time. The probability line shows that 9 heads would be thrown once in every ten times,

11 heads once in every 100 times, while once in 10,000 times all the coins would be thrown as heads.

King, in his "Elements of Statistical Method," page 103, gives similar results obtained by throwing three dice 196 times.

Merriman, on page 172 of his "Least Squares," gives as an example of frequency the results of measurements of the height of 18,780 soldiers. These results plotted on probability paper are shown in Fig. 9. It will be noticed that the points fall almost exactly on a straight line. This line shows the median height

FIG. 6.



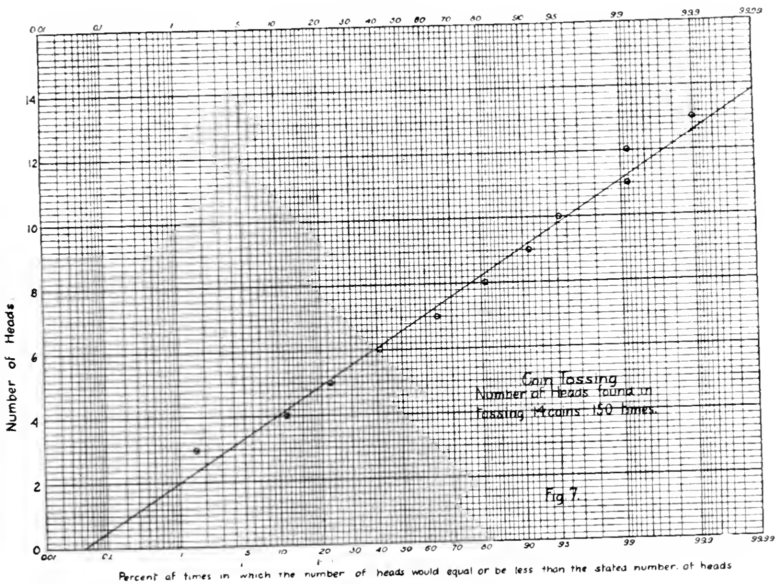
Coefficients of expansion of binomial theorem plotted on probability paper.

to be 5 feet 7 inches. One soldier in ten had a height of 5 feet 3½ inches, one in every hundred a height of 5 feet 1 inch, and it may be inferred, from the extension of the line, that one soldier in every 10,000 would have a height of only 4 feet 9½ inches. On the other hand, one soldier in every ten had a height of 5 feet 10½ inches; one in every 100 had a height of 6 feet 1 inch, and one in every 10,000, 6 feet 4½ inches. Again, the probability line shows that a height of 6 feet or more was found 2.6 per cent. of the number of times; that is, one soldier in 38 was 6 feet or more in height.

Fig. 10 shows the ages of scholars in a certain grade in the schools of St. Louis. It will be seen that the ages varied from 11 to 18, the median age being 13.8. The various points fell nearly on a straight line. The probability line shows that half of the scholars in this grade were between the ages of 13 and 14.6 years, while 90 per cent. of them were between the ages of 11.8 and 15.8.

In Fig. 11 the annual rainfalls at Boston, Mass., have been plotted for a period of 91 years, the figures being taken from the

FIG. 7.



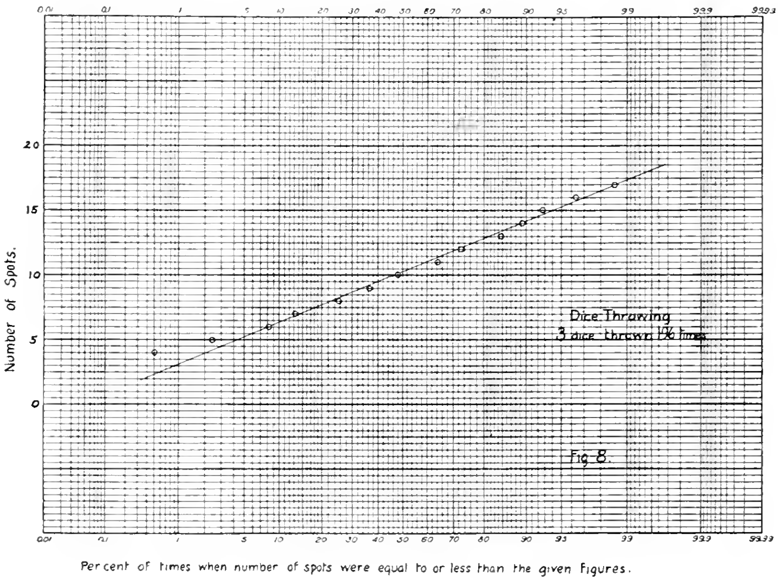
Results of coin tossing plotted on probability paper.

records of the United States Weather Bureau. They show that the median rainfall during this period was 44.5 inches. In one year in every ten the rainfall was less than 34 inches, and in one year in every ten it was greater than 54.5 inches. From the probability line an annual rainfall as low as 20 inches might be expected once in every 1000 years, and a rainfall of 75 inches or more might be expected once in every 10,000 years.

In Fig. 12 will be found similar rainfall records for Philadelphia. This series also covers a period of 91 years, and the points fall nearly on a straight line, except in the case of a few of the

wettest years. At Philadelphia the median rainfall was found to be 42 inches. In 10 per cent. of the years the rainfall was less than 33.5 inches, in 10 per cent. of the years it was greater than 51 inches. From the probability line it may be inferred that a rainfall as low as 17 inches or as high as 67 inches may occur once in 10,000 years. This method of study gives no idea as to when these high or low rainfalls may occur.

FIG. 8.



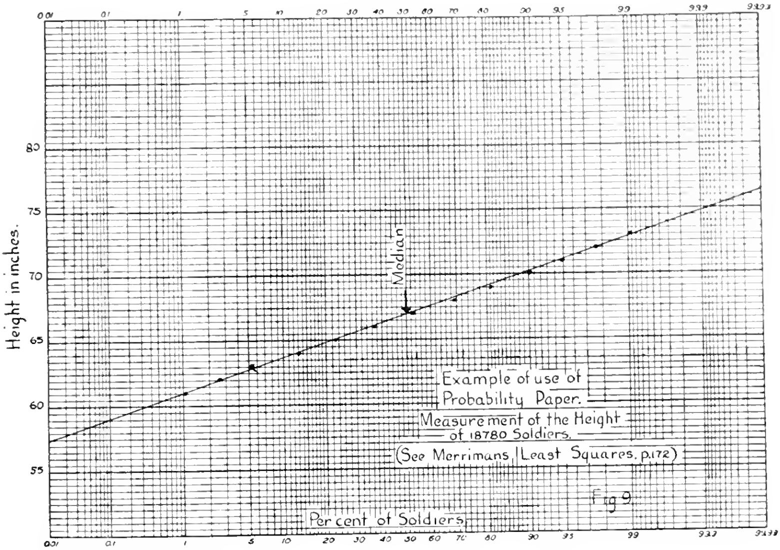
Results of dice throwing plotted on probability paper.

Fig. 13 shows the use of probability paper as applied to stream flow by Allen Hazen.[3]

Death-rates of Cities and Towns.—It has been found that if the death-rates of the cities of Massachusetts for any given year or for a term of years are plotted on arithmetic-probability paper, the results fall nearly in a straight line. This is shown by Fig. 14 for the year 1910. During this year the median death-rate for Massachusetts cities was 15.6 per 1000, and on the basis of the probability line one city in every ten had a death-rate higher than 19.5, while one city in every ten had a death-rate less than 11.7. A line of

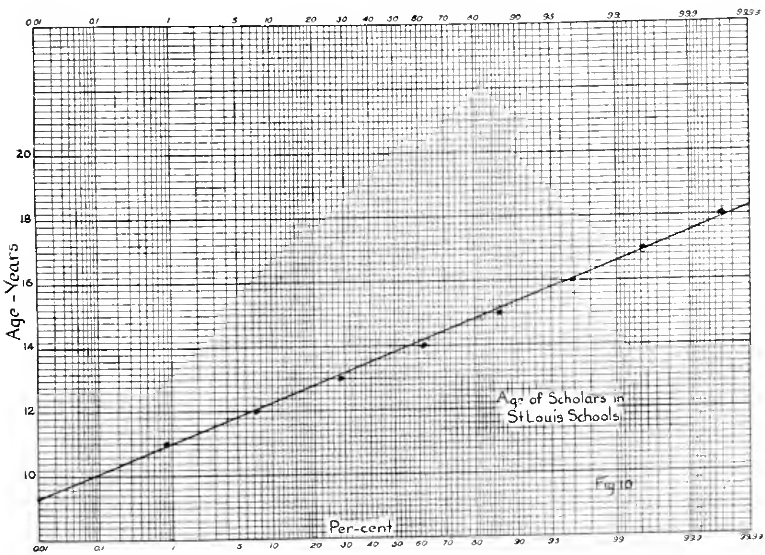
[3] *Loc. cit.*

FIG. 9.



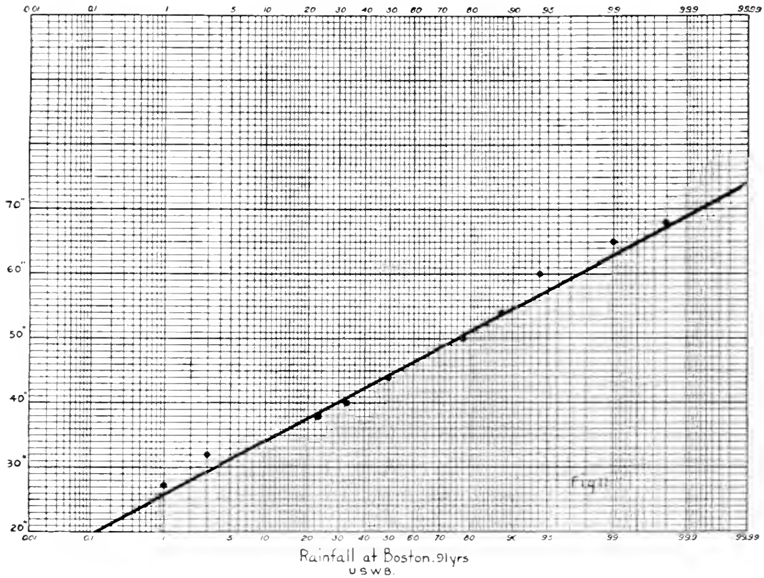
Measurement of height of soldiers plotted on probability paper.

FIG. 10.



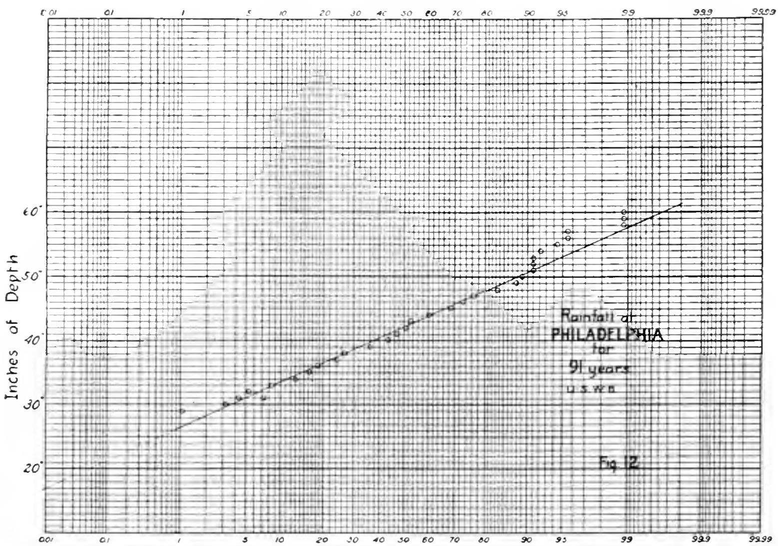
Age of scholars plotted on probability paper.

FIG. 11.



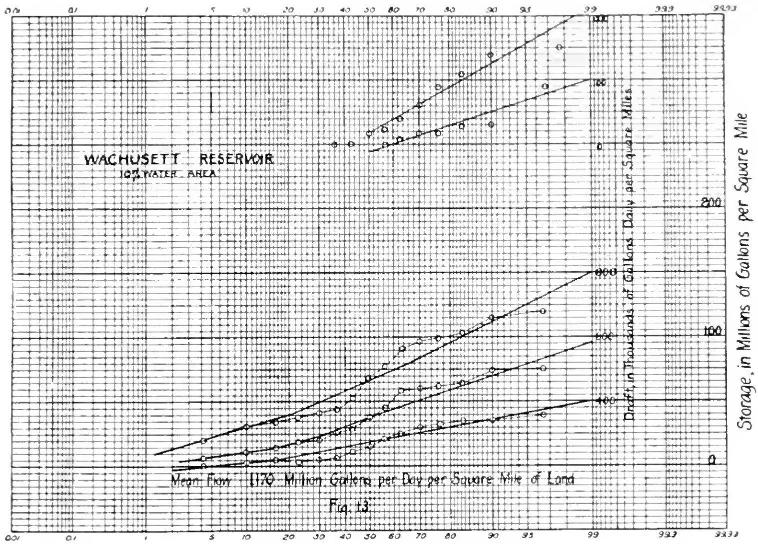
Annual rainfall plotted on probability paper.

FIG. 12.



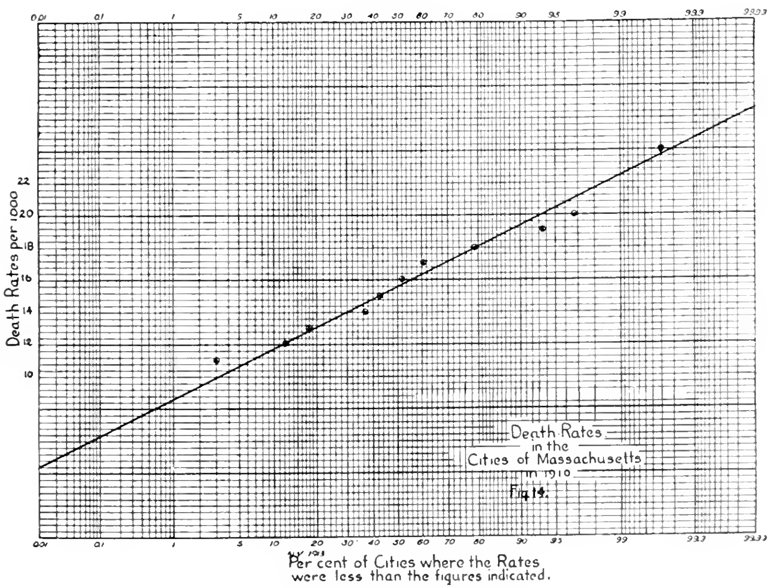
Annual rainfall plotted on probability paper.

FIG. 13.



Stream flows plotted on probability paper.

FIG. 14.

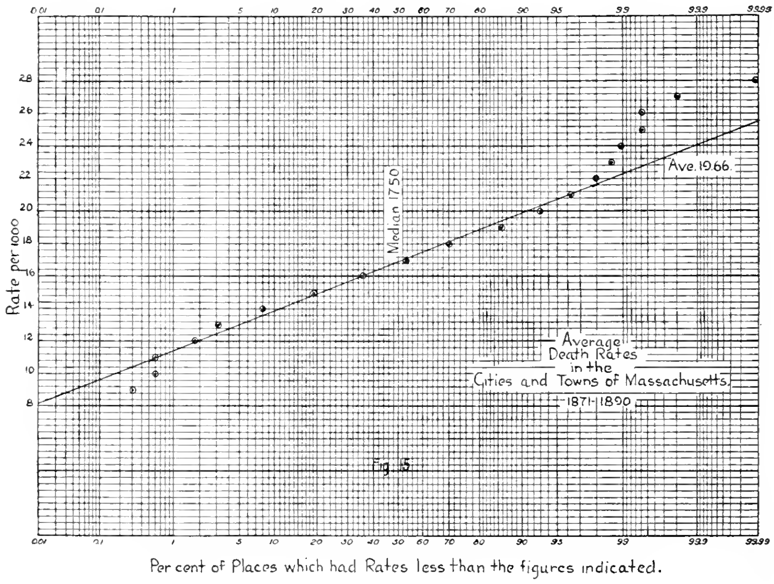


Death-rates plotted on probability paper.

this sort gives a better indication of the prevailing death-rates in the state than any mere average of the results could possibly do.

Fig. 15 shows a similar probability line for the average death-rates in the cities and towns of Massachusetts for the period from 1871 to 1890. During this period the average of the death-rates was 19.66, but the median was only 17 per 1000. It is evident that during that period abnormally high death-rates in a few places influenced the average. During this period 90 per cent. of the death-rates of the cities were between 13 and 23 per 1000. Again,

FIG. 15.



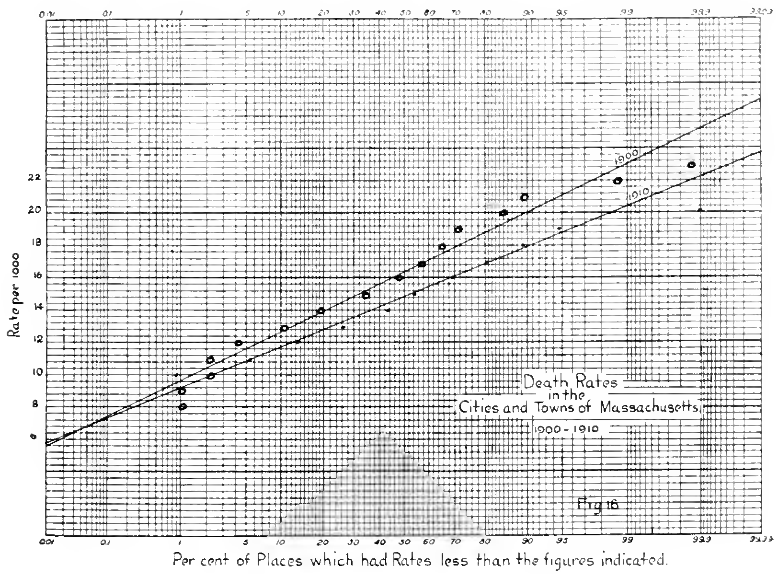
Death-rates plotted on probability paper.

in Fig. 16 we see that during the year 1900 the average death-rate for cities and towns was 18.26, the median 16.4, and 90 per cent. of the death-rates were between 11.6 and 21. But in 1910 the average death-rate had fallen to 16.04 and the median to 14.8, while 90 per cent. of the death-rates lay between 10.8 and 18.4. The lower position on the sheet of the line for the year 1910 indicates that in that year the death-rates were generally lower during 1910, while the latter slope of the line shows a greater uniformity than in 1900. It is evident that during the ten years from 1900

to 1910 the cities and towns which previously had high death-rates reduced their rates more rapidly than those in which the death-rates had previously been lower. In Fig. 17 some of the data previously mentioned are expressed in terms of percentages of the mean, and it is evident that in any year one city in every ten is likely to have a death-rate nearly 25 per cent. greater or less than the median.

Fig. 18 shows the probability lines for the death-rates of the

FIG. 16.



Death-rates plotted on probability paper.

entire state of Massachusetts for three periods, 1860–70, 1880–90, and 1900–12. It will be noticed that the rates have been becoming more uniform in recent years. In the first period there was a probable variation of the death-rate in any year from the 11-year median of 10 per cent. one year in every decade; in the second period this was only 3.5 per cent., and in the third period only 2.5 per cent. The medians were respectively 23.61, 24.02, and 18.60 per 1000.

(To be continued)

Breech Mechanisms for Guns. ANON. (*The Times* (London) *Engineering Supplement*, No. 498, April 28, 1916.)—Rapidity of gun-fire depends chiefly upon the speed with which the breech block or plug is removed and replaced as often as a shell is inserted and fired. Since the pressure which the block has to resist is very high, amounting to from 14 to 17 tons per square inch of its surface, the fitting must be close and secure, and the material used must be of high grade. The wear and tear of the parts of the mechanism, which will often total a hundred separate pieces, is very severe in all quick-firing guns, and has to be provided for by the strictest attention to material and workmanship. In most modern guns the breech fitting consists of a screw, for it is almost the only fastening that can satisfy the requirements of ample resistance to the pressure employed, coupled with easy removal and adapted to the employment of an effective gas check and convenient priming arrangements. The various actions of operation must be accomplished by single movements of a lever or hand-wheel, so that they may be embodied in the mechanism itself.

Only two methods of closing a breech have been practised, one consisting of a screw inserted axially in the breech, and the other a wedge thrust in a slot in a direction transversal to the bore. The Krupp breech block is a notable example of the wedge form. The action is simple. The wedge includes on its length a plain blank portion which seals the bore of the gun and the passage through which the charge is passed into it. The Krupp sliding wedge has been sharply criticised by the artillerists of countries which adopt the screw breech, on the ground that it does not provide a reliable form of gas check.

The serious objections to the wedge system induced British and French artillerists to adopt the axial design of breech block having an interrupted screw, a swinging console, and the de Bauge design of gas check, named after a French officer, Colonel de Bauge, who remodelled and improved it. Actual screw designs have undergone but slight variations, chiefly in the number of interruptions and in the longitudinal sections. Operating mechanisms have been and are extremely varied, but, while they possess apparently many complications, they are most simple and rapid in action.

NOTE ON THE APPLICABILITY OF THE PAPER PULP FILTER TO THE SEPARATION OF SOLIDS FROM LIQUIDS.*

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INTRODUCTION.

Of the materials used in analytical work for the separation of liquids from precipitates, filter-paper and asbestos are the best known, while filters of cloth, wool, cotton, silk, etc., are ordinarily employed in work other than analytical. Whereas, paper pulp may have been used in a few cases for special purposes, it is noteworthy that the pulp filter, which has been shown by E. H. Kellogg and the writer to be generally applicable to quantitative [1] analysis, is—so far as we are aware—not even mentioned in voluminous text-books of analytical chemistry, such as Fresenius,[2] Treadwell,[3] Hoppe-Seyler,[4] and others. Even in Abderhalden's up-to-date "Handbuch der biochemischen Arbeitsmethoden," made up of not less than ten volumes with a total of about eight thousand pages, the paper pulp [5] is mentioned in but three sentences. In the Handbuch, however, the pulp is not as such recommended for the filtration of fine precipitates, like barium sulphate, but *in connection with paper filters.*

IMPORTANCE OF A GOOD FILTER FOR ANALYTICAL WORK.

The analytical chemistry is largely based upon estimation of precipitates. While volumetric, acidimetric, and, especially, colori-

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* Published by permission of the Secretary of Agriculture and communicated by the Author.

[1] Jodidi, S. L., and Kellogg, E. H., *Jour. Ind. and Engin. Chem.*, **8**, 317, 1916.

[2] Fresenius, "Quantitative Analysis," vol. 1, p. 88, 1903.

[3] Treadwell, "Analytical Chemistry," vol. ii, p. 16, 1907.

[4] Hoppe-Seyler's "Handbuch der Physiol.-Pathol. Chem. Anal.," p. 5, 1909.

[5] "Handbuch der biochemischen Arbeitsmethoden," by Emil Abderhalden, vol. 1, 98.

metric and nephelometric [6] methods are coming more and more into use, the quantitative and qualitative analysis is still, in most cases, dependent upon the determination of precipitates. Of all operations necessary to quantitatively obtain the precipitates in a pure form, their filtration through filter-paper is one which is not only very tedious and time-consuming, but requires also certain skill. That filtration (including decantation) takes a considerable part of the time necessary for an analysis every chemist knows from his own experience, and is also evident from the fact that the text-books of analytical chemistry usually devote much space and painstaking details to the processes of decantation, filtration, and washing of precipitates. It is, therefore, quite advantageous to make use of the pulp filter, which, in connection with a research into the chestnut [7] bark disease, was shown to be applicable to the estimation of phosphorus,[8] calcium,[9] and magnesium,[9] and to quantitative [10] analysis in general. The pulp filter permits of comparatively rapid filtration and washing, so that one is able to save considerable time and labor. A simple consideration will show why this filter permits of rapid work, combined with economy and accuracy.

RAPIDITY.

The actual filtration through an ordinary paper-filter, because it snugly rests on the walls of the funnel, takes place chiefly through a very small portion only; namely, through its conical part, which freely hangs over the stem of the funnel. As the filtration goes on, this free filtering part is gradually plugged up, which more and more retards the filtration. On the other side, the filtration on the pulp filter, whether used with a Gooch crucible or with a perforated plate, takes place through a number of holes (usually from 60 to 70), so that when some of them are plugged up during filtration the others still continue to filter well. But what seems to be of greater importance is the fact that the

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[6] Kober, P. A., and Egerer, G., *Jour. Amer. Chem. Soc.*, **37**, 2373, 1915; Kober, P. A., and Graves, E. E., *Jour. Ind. and Engin. Chem.*, **7**, 843, 1915; S. S. Graves and P. A. Kober, *Jour. Amer. Chem. Soc.*, **37**, 2430, 1915.

[7] S. L. Jodidi, *Jour. Amer. Chem. Soc.*, **37**, 1708, 1915; S. L. Jodidi and E. H. Kellogg, Jour. Franklin Institute, **180**, 349, 1915.

[8] S. L. Jodidi and E. H. Kellogg, *Biochemical Bulletin*, **5**, 87, 1916.

[9] S. L. Jodidi and E. H. Kellogg, Jour. Franklin Institute, **181**, 217, 1916; *Chemical Engineer*, **23**, 60, 1916.

[10] S. L. Jodidi and E. H. Kellogg, *Jour. Ind. and Engin. Chem.*, **8**, 317, 1916.

work with the paper pulp filter enables one to make use of suction, which, as in the case of the asbestos filter, considerably accelerates the rapidity of the filtration.

The direct experiment shows (which seems also evident) that, *cæteris paribus,* the thicker a pulp filter is, the more slowly it filters, and *vice versa.* By using, however, pulp emulsion of equal consistency—from 1.5 to 2 c.c.[11] of water for each centigramme of filter-paper—and by preparing the pulp filters in a definite way it is fairly easy to obtain filters of uniform thickness and efficiency.

To illustrate the rapidity of filtration through a pulp filter, as compared with an ordinary paper filter, it seems worth while here to arrange a few previous data in tabular form.

TABLE I.

Precipitate	Decantation, filtration, and washing of precipitate requires: On paper filter, minutes	On pulp filter, minutes	Remarks
Ammonium phosphomolybdate[12]	20–35	5	The paper filter used was an S. & S. folded filter, No. 588, of 12½ cm. diameter.
Calcium oxalate[13]......	30–35	5	
Magnesium ammonium phosphate[14]	30	3–6	The paper filter employed was an S. & S. filter, No. 590, of 9 cm. diameter.
Barium sulphate[15]......	35	10	The same paper filter was used as in the case of magnesium ammonium phosphate.
Silver chloride.........	30–40	8–15	The same paper filter was used as in the case of magnesium ammonium phosphate.
Potassium platinic chloride	40–50	15	The same paper filter was used as in the case of magnesium ammonium phosphate.

[11] S. & S. filters, Nos. 589 and 588, of 12½ cm. diameter, weigh about 0.95 and 0.8 gr. respectively. Equally, an S. & S. filter, No. 595, of 11 cm. diameter, weighs about 0.6 gr. The weight of an 11-cm. filter of common sheet filter-paper was found to be 0.75 gr. The average weight of one filter of the above descriptions—frequently used for analytical work—is about 0.75 gr., which, reduced with some 150 c.c. of water (2 c.c. water to 1 centigramme paper), gives a paper pulp which is ordinarily suitable for analytical and other purposes.

[12] Not published yet.

[13] JOUR. FRANKLIN INSTITUTE, **181**, 222, 1916.

[14] *Ibid.*, **181**, 229, 1916.

[15] *Jour. Ind. and Eng. Chem.*, **8**, 318, 1916.

ACCURACY.

For analytical purposes the accuracy of an ordinary paper filter, though half of it is threefold, is the accuracy of which just one filter layer is capable, because the other half of an ordinary filter is but single-folded. The pulp filter, on the other hand, has a manifold filtering surface, as can be seen from the following consideration. An 11-cm. filter, *e.g.* (frequently used in quantitative analysis), has a total filtering surface of 95 sq. cm., whereas a Gooch crucible (with a bottom of 2.22 cm. in diameter) has 3.87 sq. cm. of filtering surface. Hence, by using the reduced pulp of an 11-cm. filter for five Gooches, the filtering surface of the pulp filter can be made up of four or five layers. While this is not uniformly the case throughout the filter, its weakest part may safely be assumed to have not less than two or three layers. For this very reason the filtrates from pulp filters are, as a rule, much clearer than those from paper filters and comparatively seldom need refiltration.

ECONOMY.

The above calculation shows that the pulp of a filter of 11-cm. diameter is sufficient for four or five Gooches, *i.e.*, for four or five quantitative analyses, which stands in agreement with the

Table II.

Paper filters used	Diameter of filter, cm.	Economy of filter-paper obtained by reducing the paper filters to pulp, per cent.	Diameter of filter, cm.	Economy of filter-paper obtained by reducing the paper filters to pulp, per cent.	Diameter of filter, cm.	Economy of filter-paper obtained by reducing the paper filters to pulp, per cent.
S. & S., No. 588, folded[16]	9	166	11	248	12½	320
S. & S., No. 595[17]	9	201	11	300	12½	387
S. & S., No. 589...	9	190	11	284	12½	367
S. & S., No. 598...	9	300	11	448	12½	579
Commonest sheet filter-paper	9	313	11	467	12½	603
Average......	..	234	..	349	....	451

[16] The details will be published in *Biochemical Bulletin*, 5, 87–94, 1916.

[17] Jour. Franklin Institute, 181, 231, 1916.

direct experiment. This fact will readily be comprehended when we consider that at most half of an ordinary paper filter can for analytical purposes be utilized, since half of it is threefold. As the filter, however, is never filled to its upper edge, it is fair to state that from two-thirds to three-quarters of the ordinary paper filter is wasted, whereas the filtering surface of the pulp filter is fully utilized.

For the sake of convenience the results in question recalculated to filters of 9, 11, and 12½ cm. diameter, respectively, are presented in Table II.

Table II shows that when paper filters of 9, 11, and 12½ cm. diameter, respectively, are reduced with water to pulp, there results an average economy of filter-paper amounting to 234, 349, and 451, respectively, the total average being 345 per cent. This is the arithmetical expression of the experimentally-demonstrated fact that one quantitative paper filter of average thickness and size, when reduced with water to pulp, yields enough of it to cover about four Gooch crucibles with pulp filters.

THE PAPER PULP FILTER AS COMPARED WITH OTHER FILTERS GENERALLY EMPLOYED IN QUANTITATIVE ANALYSIS.

So far as quantitative analysis is concerned, good filter-paper was preferably used for the separation of precipitates from liquids. It is perfectly true that the Gooch [18] asbestos filter is extensively used in analytical work, since it offers several advantages, chief among which is the rapidity and accuracy of work, as well as the possibility of using the same asbestos filter for several consecutive determinations. But it is true, also, that, in addition to the asbestos filter, the ordinary paper filter is still employed to a great extent in analytical, synthetical, and other work. Yet it is a matter of common knowledge that paper filters, far from being a quick filtering medium, yield not infrequently turbid filtrates or even break during filtration, which necessitates repeated refiltrations. On the other hand, the pulp filter, which never breaks and permits of uniform and comparatively rapid work, gives, as a rule, clear filtrates. For these and other reasons outlined above, the paper filter should be replaced by the pulp filter, wherever pos-

[18] *Jour. Amer. Chem. Soc.*, **12**, 45 (1883); *Ber. Deutsch. Chem. Ges.*, **32**, 2142 (1899). See also Munroe crucible, *Jour. Analyt. Chem.*, **2**, 241 (1888); *Chem. News*, **58**, 101 (1888).

sible, since the latter offers many advantages. It retains [19] fine precipitates, such as ammonium phosphomolybdate, calcium oxalate, etc., more readily than a paper filter or a new asbestos filter. It is more accessible, easier to handle, and requires less time and skill for its preparation than the asbestos filter. The work with the pulp filter is more convenient and more rapid than with the paper filter. The fact that the use of the pulp filter enables one to make considerable saving of filter-paper is at present especially significant in view of the scarcity of good filter-paper in this country.

WHEN IS THE PAPER PULP FILTER APPLICABLE?

We had already occasion to indicate as to why the pulp filter is preferable to either the paper filter or asbestos filter. As to the applicability of the pulp filter, it may generally be stated that it is applicable wherever the ordinary paper filter can be used. Thus it was demonstrated in previous papers [20] that the pulp filter can be used for the quantitative estimation of the acids—phosphoric, hydrochloric, sulphuric; and of the bases—potassium, ammonium, barium, calcium, magnesium, silver; and for quantitative analysis in general. It is a matter of course that it can be applied also to qualitative analysis, to preparation work, or wherever crystallized or more or less crystalline precipitates have to be separated from neutral or moderately acid and alkaline liquids. The paper pulp filter, however, should not be used for the filtration of strongly acid or alkaline liquids (which holds also true for the ordinary paper filter), in which case filters of asbestos or glass wool are preferable; nor should the pulp filter be used for separation of colloidal substances.

For the filtration of very small precipitates—from a few milligrammes down to one milligramme or less—contained in a small volume of liquid, the common paper filter of small size may in some cases be preferred. Especially will this be the case whenever it is essential to have the substance absolutely free from paper fibre

[19] That precipitates like calcium oxalate, barium sulphate, and ammonium phosphomolybdate frequently pass through filter-paper is so well known a fact that we here need not dwell upon it. See, in this connection, S. L. Jodidi and E. H. Kellogg, Jour. Franklin Institute, **181**, 228, 1916, footnote; *Biochem. Bulletin*, **5**, 87–94, 1916.

[20] *Loc. cit.*

On the other hand, the pulp filter will render very good services for the refiltration of considerable quantities of not quite clear liquids, or for the separation of comparatively large quantities of liquids from small precipitates.

It may be emphasized here that whether a single analysis or series of them are to be made, the pulp filter offers distinct advantages, because it enables one to accomplish the work in less time with less filtering material and with just as accurate results as can be obtained with good paper filters.

CONCLUSIONS.

1. The reasons are outlined in detail as to why the pulp filter (whenever applicable) is superior to the paper filter and asbestos filter—the economy of filter-paper, rapidity and accuracy of work, and easy accessibility being the most important factors involved in the use of the pulp filter.

2. The instances are definitely stated as to when the pulp filter is applicable, or is to be used in preference to either the paper filter or asbestos filter.

Bureau of Plant Industry, U. S. Department of Agriculture,
WASHINGTON, D. C., April, 1916.

The Unit of Viscosity Measurement. P. C. MCILHINEY. (*The Journal of Industrial and Engineering Chemistry*, vol. 8, No. 3, May, 1916.)—The scientific world expresses the results of measurements of viscosity in terms of absolute viscosity, of which the units are directly related to the fundamental units of mass, length, and time. The practical world speaks of Saybolt seconds, Engler numbers, etc. The absolute C. G. S. unit of viscosity is a relatively large one, so that water and similar liquids have absolute viscosities that are inconveniently small numbers, and, furthermore, without giving it a name, it is impracticable to use such a unit in commercial testing. The study of this important physical property of liquids has been seriously hampered by the lack of any kind of uniformity in its measurement, and only a few workers know how to translate the results which they obtain into results comparable with those obtained with another instrument.

The suggestion has been made by Deeley and Parr that the unit of viscosity expressed in C. G. S. units should be called the "poise," in honor of Poiseuille, but the suggestion has not been adopted generally, and it is customary to simply speak of the "absolute" viscosity of a liquid. If the "poise" is adopted as the name of the absolute

unit, it has been suggested that we might use the decimal multiples and submultiples of this unit, and that then the centipoise—1 cp = 0.01 p—could be almost exactly the viscosity of water at 20° C. or 68° F. Thus for all practical purposes in the lubricating oil business it would be sufficiently near the truth to say that the viscosity expressed in centipoise is the specific viscosity; that is, the viscosity as compared with water at 20° C. as a standard liquid. The true viscosity of water in absolute units is 1.0042. Tables have been prepared by the use of which the true viscosity may be calculated from the number of seconds required with such extensively used instruments as the Saybolt Universal, Engler, and Redwood viscosimeters.

Steel in Wrought-iron Pipe. ANON. (*Iron Age*, vol. 97, No. 19, May 11, 1916.)—The detection of steel by means of etching with picric acid and a microscopical examination requires the preparation of a metallographic specimen and is a tedious operation, involving considerable time and the exercise of great care. Even when the wrought iron contains a large percentage of steel, the steel contents may often be missed, as there is nothing to indicate where the metallographic specimen should be prepared for microscopic examination. The test here described, developed by the A. M. Byers Company, of Pittsburgh, eliminates this uncertainty. It is not in itself conclusive as to the presence of steel, but by defining the areas most likely to contain steel it eliminates the necessity for further search and enables the investigator to proceed at once with the more elaborate preparation of the specimen for microscopic examination.

Three or four sample rings two or three inches in length are cut from different points of the pipe. The rings are submerged, one at a time, in a solution consisting, by volume, of hydrochloric acid 25 per cent., sulphuric acid 25 per cent., and water 50 per cent. After being left in the solution about one minute, the samples are rinsed in cold water and then with alcohol. Both ends of each sample should then be examined to discover bright streaks which are indicative of steel in the metal. As a rule, an examination of the surface of the metal will not show steel, as steel scrap is usually inserted in the middle layers of the fagot to prevent it from coming to the surface of the finished pipe. If no suspicious-looking streaks are found in the first ring etched, additional rings are tried. Three or four will usually reveal the steel scrap, especially if rings cut from different pieces of pipe are available. A "flat" or smooth surface is filed on the outside of the ring suspected of containing steel from the appearance of the end indications. Filing is stopped when the suspected steel band or bands are half filed away or when their maximum surface is exposed. It is not necessary to polish the surface to be examined. The flat is now etched in the same manner as the ends to disclose the steel bands. If any doubt now exists as to the composition of the bright streaks, the surface may be polished and etched with picric acid for microscopic examination.

PRESENTATION OF THE FRANKLIN AND ELLIOTT CRESSON MEDALS, MAY 17, 1916.

AT the stated meeting of the Committee on Science and the Arts, held March 1, 1916, the following resolutions were adopted:

Resolved, That the Franklin Medal be awarded to Theodore William Richards, Chem.D., M.D., Ph.D., Sc.D., LL.D., in recognition of his numerous and important contributions to inorganic, physical, and theoretical chemistry, and particularly his classical series of redeterminations of the atomic weights of the more important chemical elements.

Resolved, That the Franklin Medal be awarded to John J. Carty, E.D., D.Sc., in recognition of his long-continued activities in the telephone service, his important and varied contributions to the telephone art, his work in the establishment of the principles of telephone engineering, and his signal success in directing the efforts of a large staff of engineers and scientists to the accomplishment of the telephonic transmission of speech over vast distances.

Resolved, That the Elliott Cresson Medal be awarded to the American Telephone and Telegraph Company in recognition of its constructive and far-seeing policy in the development of the art of telephony; in the promotion of telephone engineering; in the establishment of its telephone system in every part of the United States, and for placing all of the States of the Union in speaking communication.

CORRESPONDENCE WITH MEDALLISTS.

THE FRANKLIN INSTITUTE.

PHILADELPHIA, PA., March 4, 1916.

Prof. Theodore William Richards,
Harvard University,
Cambridge, Mass.

SIR:—

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> *Resolved,* That The Franklin Medal be awarded to Theodore William Richards, Chem.D., M.D., Ph.D., Sc.D., LL.D., in recognition

of his numerous and important contributions to inorganic, physical, and theoretical chemistry, and particularly his classical series of redeterminations of the atomic weights of the more important chemical elements.

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 17, to receive this medal and certificate from our President.

I am,

Respectfully,

(Signed) R. B. OWENS,

RBO : HMS *Secretary.*

WOLCOTT GIBBS MEMORIAL LABORATORY, HARVARD UNIVERSITY.

THEODORE WILLIAM RICHARDS,
Director.

CAMBRIDGE, MASS., U. S. A., March 6, 1916.

Dr. R. B. Owens, Secretary,
The Franklin Institute of the State of Pennsylvania,
Philadelphia, Penna.

SIR:—

In formal acknowledgment of your favor of March 4, I beg to express my very high appreciation of the honour accorded to me by The Franklin Institute by the award of The Franklin Medal. This award is a great gratification to me, not only because it is the highest gift of this kind awarded by my native city, but also because I feel it is an especial honour to head the list of the American Franklin medallists for pure science.

I accept with pleasure the cordial invitation of the Institute to come to Philadelphia on May 17 to have the honour of receiving the medal and certificate from the President.

I beg to remain, my dear sir,

Sincerely yours,

(Signed) T. W. RICHARDS.

THE FRANKLIN INSTITUTE.

PHILADELPHIA, PA., March 14, 1916.

John J. Carty, Esq., E.D., D.Sc.,
American Telephone and Telegraph Company,
New York, N. Y.

SIR:—

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in

physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> *Resolved,* That The Franklin Medal be awarded to John J. Carty, E.D., D.Sc., in recognition of his long-continued activities in the telephone service, his important and varied contributions to the telephone art, his work in the establishment of the principles of telephone engineering, and his signal success in directing the efforts of a large staff of engineers and scientists to the accomplishment of the telephonic transmission of speech over vast distances.

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 17, to receive this medal and certificate from our President.

I am,

Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO : S

FIFTEEN DEY STREET.

NEW YORK, March 17, 1916.

Dr. R. B. Owens, Secretary,
The Franklin Institute,
Philadelphia, Penna.

DEAR SIR:—

I have the honor to acknowledge the receipt of your communication of the 14th of this month, advising me that The Franklin Institute has awarded to me The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications.

I take this first opportunity to express to The Franklin Institute my grateful appreciation of this great distinction which it has so generously conferred upon me. Knowing the jealous care with which this honor is bestowed and understanding the high standards to which the holders of this medal must conform, my feelings of pleasure and satisfaction and gratitude have been accompanied by the resolve to do everything in my power to be worthy of enrolment among the Franklin medallists.

It gives me great pleasure to say that I accept the cordial invitation which you have extended to me on behalf of the management to come to the Institute on Wednesday, May 17, to receive The Franklin Medal and certificate from the President.

As a slight token of appreciation on the part of my company and on my own part, I am making plans for a telephone demonstration as a part of the ceremonies attending the presentation of the medal, which will exemplify the advancement in the art of telephony, which has received such distinguished recognition from The Franklin Institute. I shall communicate with you within a short time concerning the nature of the telephone demonstration and shall be glad to receive your suggestions in regard to it.

Meanwhile permit me to thank you for the most courteous consideration which you have shown to me.

Very sincerely yours,

JJC-EMR (Signed) JOHN J. CARTY.

THE FRANKLIN INSTITUTE.

PHILADELPHIA, PA., March 8, 1916.

Theodore N. Vail, Esq., President,
American Telephone and Telegraph Company,
New York City, N. Y.

SIR:—

I have the honour to inform you that The Franklin Institute has awarded to the American Telephone and Telegraph Company its Elliott Cresson Medal, founded in 1848 for the "recognition of discovery or original research adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery and invention, and methods or products embodying substantial elements of leadership in their respective classes."

The award is minuted as follows:

> *Resolved,* That the Elliott Cresson Medal be awarded to the American Telephone and Telegraph Company in recognition of its constructive and far-seeing policy in the development of the art of telephony; in the promotion of telephone engineering; in the establishment of its telephone system in every part of the United States, and for placing all of the States of the Union in speaking communication.

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 17, to receive this medal and certificate from our President.

I am, Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO : S

15 DEY STREET,
NEW YORK.

March 9, 1916.

R. B. Owens, Esq.,
Secretary, Franklin Institute,
Philadelphia, Pa.

MY DEAR SIR:—

I beg leave to acknowledge the receipt of yours of March 8.

The honor which your Institute has decided to confer upon the American Telephone and Telegraph Company will be appreciated very highly, and unless something arises which will make it absolutely impossible, you may be sure that I shall be present on May 17.

This is not an official acknowledgment, but merely a personal acknowledgment to you of the receipt of your letter.

I have instructed our people to send you a printed copy of the address delivered at the Geographic Society Banquet as soon as it comes from the printer.

Sincerely yours,
(Signed) THEODORE N. VAIL.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
15 Dey Street.

NEW YORK, March 22, 1916.

Mr. R. B. Owens, Secretary,
The Franklin Institute,
Philadelphia, Pennsylvania.

DEAR SIR:—

Your letter of the 8th instant, advising us that The Franklin Institute had awarded to this company its Elliott Cresson Medal, was acknowledged by President Vail before his departure for the South, and handed to me for further attention.

The Board of Directors of this company, at a meeting held yesterday, directed me to convey to you and to The Franklin Institute an expression of this company's appreciation of the great honor bestowed upon it by your distinguished society, and to say that this recognition of the company's efforts to realize its desire to be of service to the American people is exceedingly gratifying, and will be a source of inspiration to our entire organization.

Respectfully yours,
(Signed) U. N. BETHELL,
Senior Vice-President.

PROGRAMME OF MEETING, MAY 17, 1916.

Presentation of the Franklin Medal to THEODORE WILLIAM RICHARDS, Chem.D., M.D., Ph.D., Sc.D., LL.D., Director, Wolcott Gibbs Memorial Laboratory, Harvard University.

Address by Dr. Richards, "The Fundamental Properties of the Elements."

Presentation of the Franklin Medal to JOHN J. CARTY, E.D., D.Sc., Chief Engineer American Telephone and Telegraph Company.

Address by Dr. Carty, "The Telephone Art."

Presentation of the Elliott Cresson Medal to American Telephone and Telegraph Company, Theodore N. Vail, President.

Address by Mr. Vail.

PRESENTATION OF THE FRANKLIN MEDALS TO DOCTORS THEODORE WILLIAM RICHARDS AND JOHN J. CARTY.

In calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest awards in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Professor Richards:

"*Mr. President:* We are gathered here this afternoon in this venerable Hall to witness the formal presentation by you, on behalf of The Franklin Institute, of the highest awards within its gift to those distinguished men whom the Committee on Science and the Arts has this year chosen and recommended as most worthy of such honor in view of their great achievements in science.

This is the second occasion on which two impressions of the beautiful Franklin Medal are presented by you in accordance with the wishes of the founder, Samuel Insull, Esq., who in his deed of gift has stipulated that "it shall be awarded from time to time to those workers in physical science and technology, without regard of country, whose efforts, in the opinion of the Institute, have done most to advance our knowledge of physical science and its applications." It is a matter of great and peculiar gratification to our Institute, Mr. President, that in this instance both of the medallists should be Americans, representing, as they do, the

highest achievements—in the one case, of research and discovery in pure science, and, in the other, in the practical applications of physical science.

On the other side of the Atlantic the terrible war has most seriously interfered with—nay, almost halted—scientific progress: it has directed scientific knowledge and human ingenuity in the belligerent countries toward the devising of instruments of destruction, instead of their normal mission of advancing civilization. But it is quite improbable that even if by some miracle this devastating struggle could have been prevented, and the work of scientists had been allowed to proceed along the former lines, even then, I say, it is unlikely that our choice of medallists would have been different. We are satisfied that, without making any reservation or allowance for the present conditions in Europe, they must be counted as luminaries of the first magnitude among living scientists.

I consider it a great privilege, Mr. President, to represent the Science and Arts Committee and to introduce the medallists on this occasion.

In spite of the vast expenditures for their armies and navies in times of peace, the governments of European countries have long realized that liberal appropriations to their institutions of learning and for the promotion of scientific research is money well invested: in our country, on the other hand, the endowment of universities and research laboratories is largely dependent upon the munificence of private individuals. Nevertheless, the advancement of science in American laboratories, and by American workers, especially in recent years, has been quite abreast of that in European countries; and in not a few branches of science we are proud to point to our compatriots as the peers of those abroad. The eminent chemist who is to receive the Franklin Medal is a striking case in point. Though still in the prime of life, and looking forward, perhaps, to even greater achievements, his contributions to chemical science are universally recognized as second to none, either in number or importance, made by any contemporary investigator. Only recently the Nobel Prize of 1914 in chemistry was awarded to him, and the oldest and most famous institutions of learning in every part of the world have fairly showered upon him their highest honors and distinctions. More than a dozen universities have conferred upon him their

honorary degrees; learned societies, both here and abroad, have vied with one another in electing him a member or officer; and the most highly prized trophies of chemistry, such as the Davy, the Faraday, and the Willard Gibbs Medals, have been bestowed upon him. With the award of the Franklin Medal the last great link in this great chain of honors would seem to be added.

And it seems peculiarly appropriate that this should be done in his native city. He was born in Germantown, in 1868, the son of a well-known painter of landscapes and marines. It was there, also, that he spent most of his childhood, and where his gifted mother conducted his early education. His curiosity and interest in experimentation and science were early awakened by friends of the family, among them Dr. John Marshall, of the University of Pennsylvania. At the age of fifteen he entered the Sophomore class at Haverford College, where he first seriously studied chemistry under Dr. Lyman B. Hall. After graduation in 1885, he studied Greek and entered the Senior class in Harvard, as its youngest member, in the autumn of the same year.

Since then his career, with the exception of a few and comparatively short interruptions, has had its scene in Harvard University. Graduating as A.B. in 1886, *summa cum laude*, with highest honors in chemistry, he received a fellowship in the graduate department and conducted research work under Josiah Parsons Cooke, taking the degrees of A.M. and Ph.D. in 1888. The following year he spent in Europe, visiting eminent chemists and important laboratories in various countries, and familiarizing himself with special methods of analysis and research. Returning to Harvard in 1889, he was appointed assistant, and from this position he gradually rose to that of Professor of Chemistry and Director of the recently founded Wolcott Gibbs Memorial Laboratory. The only prolonged absences from Harvard were for the purpose of studying with some of the German masters, and, in 1907, when he was selected as Visiting Professor to the University of Berlin. Teaching a group of advanced students his methods of experimentation and research, he made a profound impression on both the students and professors. It was little short of a revelation to the German chemists that the time had arrived for reciprocity between the American and German universities in the teaching of the most advanced thought and practice in chemical research.

To sketch and characterize the work of our medallist in a few sentences—and that is all I can here attempt to do—is a difficult, an almost hopeless, task. If you consider that ever since he graduated from Harvard in 1886 he has continuously and indefatigably been active as a teacher and investigator; that his fertile brain has planned and directed the work of great numbers of assistants and students; that his contributions to science extend over vast domains of inorganic, physical, analytical, and theoretical chemistry, and in many cases far beyond the border-line of physics; if you consider how numerous, divergent, and extended are the paths he has travelled, you will understand that only a very few of the high lights can here be pointed out. Best known, and, in certain respects, most important, are the researches on the atomic weights of more than twenty of the chemical elements. These elements were not chosen at random, but very carefully selected with a view to solve chemical problems of fundamental importance. The papers published on this work extend over many years, and must be counted among the classics of chemical literature. They reveal the masterly reasoning of the author, his fertile scientific imagination, his resourcefulness and skill as an experimenter. They abound in the description of new observations, new methods, and new forms of apparatus. The atomic weights themselves are determined with the utmost precision that the resources of modern science permit. It was from the investigation of the fundamental properties of the elements that most of his other researches took their starting-points. Among them are the studies of the compressibility of elements and compounds; of the changes in atomic volume; of the birth of crystals as revealed by micro-photography and the kinetoscope; of thermochemical, electro-chemical, and, lately, also of radio-chemical problems. His hypotheses concerning the sour taste of acids and the compressibility of atoms are noteworthy contributions to theoretical chemistry, and he has also devised one of the best methods of teaching elementary chemistry.

I am aware, Mr. President, that this brief summary is far from adequate to impress you and this brilliant audience with the far-reaching importance of our medallist's work in the light it has shed upon the fundamental properties of the elements and upon the relationships of matter and energy. I trust, however, that these deficiencies will be made up when we listen to the address the

medallist, Dr. Theodore William Richards, has prepared for this occasion."

Due to illness, Dr. Richards was unable to be present, and the President announced that the medal and accompanying certificate would be forwarded to him. Dr. George A. Hoadley then read the following address for Professor Richards:

THE ESSENTIAL ATTRIBUTES OF THE ELEMENTS.

BY

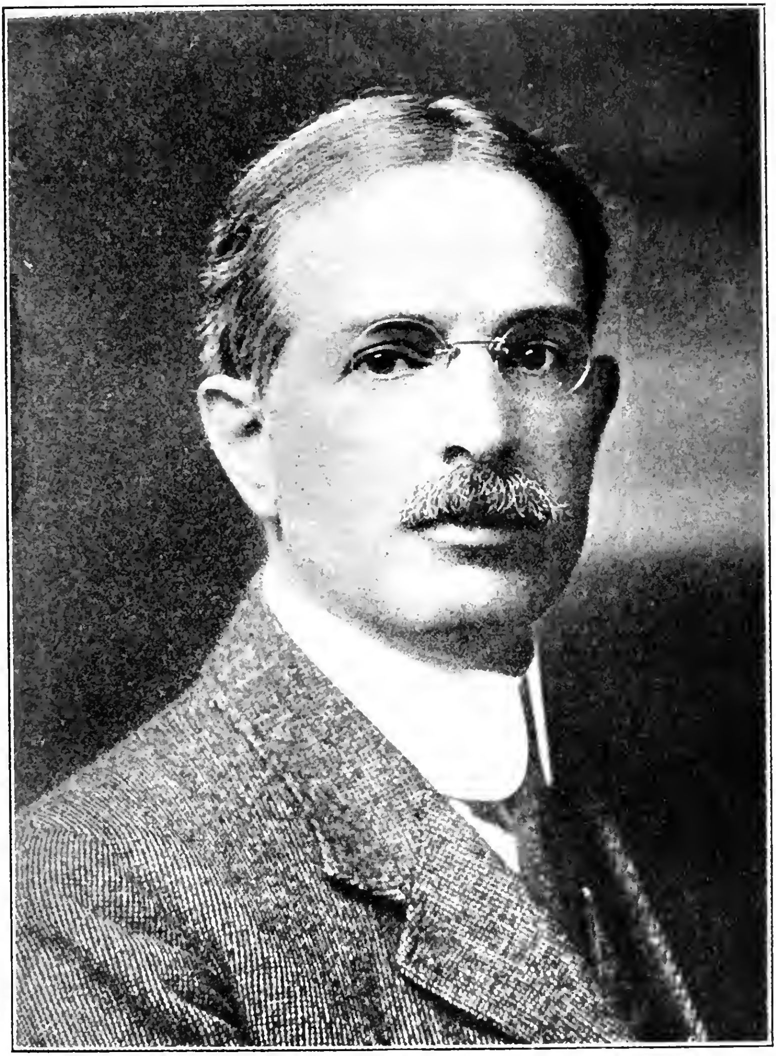
THEODORE W. RICHARDS, CHEM.D., M.D., PH.D., SC.D., LL.D.,

Director, Wolcott Gibbs Memorial Laboratory, Harvard University.

We come together to-day, in this world-renowned Institute, founded in honor of one of the greatest of our countrymen, to participate in an annual celebration of progress in pure and applied science. Franklin himself would have heartily approved of such an annual celebration; he was deeply interested in the study of Nature, and profoundly convinced of the importance to humanity of exact knowledge and its practical application. Inspired by his conviction of the usefulness of science, he founded here in Philadelphia the oldest American scientific society, and here he performed the first significant experiments in physics of the New World. He would have eagerly supported the Institute in its aims and activities, and he is fittingly commemorated in its name.

To be included in this celebration of scientific advance in the home of Franklin, my own native city, is a privilege; and I beg to express my hearty appreciation of the very great honor which the Institute has conferred upon me.

As the title on the program indicates, my pleasant duty now is to speak to you on the fundamental properties of the elements, which have formed the chief subject of my chemical and physical studies. At the outset one may well ask: What are the elements, and what shall we designate as their fundamental properties? In these iconoclastic days several of our old scientific idols seem to have been shattered. If uranium and radium are only transitory, may not the other so-called "elements" also be slowly decomposing? In this case, ought we to count them as elements at all? Moreover, if, as some suppose, the atom is made up of nothing but electrons (positive and negative), what has become of the old atomic theory?



T. W. Richards

These questions, disturbing although they may seem to be, are easily answered. Perhaps, from a philosophical and etymological point of view, the chemical atom no longer deserves its name; but the fact remains that in all the ordinary affairs of life our relations with the chemical elements primarily concerning us are unchanged by all the fascinating new knowledge. These same old elements remain as permanent as they ever were; and the only satisfactory explanation of the definite proportions by weight in which they combine is now, as of yore, the assumption of ultimate, undestroyed (if not indestructible) particles or chemical "atoms." The atomic theory is indeed even more convincing to-day with regard to mundane chemical affairs than it was before the dawn of radio-activity.

Of course, no one pretends nowadays that the chemical elements are to be considered as absolutely incapable of decomposition. Even supposing, however, that in the hottest stars some of them disintegrate, on earth, at least, they are amazingly permanent. It is concerning the earthly chemical elements, therefore—the old-fashioned kind of half a century ago—that I have to speak.

These elementary chemical substances build up everything about us, as well as our own bodies. It has always seemed to me, therefore, that the fundamental attributes which determine their behavior are worthy of very careful scrutiny.

Among the most fundamental of attributes, if not the most significant of all, is the tendency possessed by the elements to combine in definite proportions by weight. This we explain, as already stated, by the assumption that all matter is made up of atoms. One cannot believe that these atoms should have anything so important as their weight decided by mere chance or accident. Therefore, I chose the study of the atomic weights as the first of the fundamental properties to be investigated, and perhaps half of my time during the last thirty years has been devoted to this subject.

Great accuracy in the work was sought for several reasons, the most important of which was an earnest desire to find if possible the suspected mathematical relationship between these fundamental quantities. Such a relationship, if discovered, would greatly deepen our insight; and if it is to be found, the data to be compared must be determined as accurately as possible.

Another reason for taking great pains in determining atomic

weights is the fact that these figures are used by chemists throughout the world in their daily work oftener than any other series of data. All the manifold happenings of Nature occur in material built up of these same atoms. If we are to analyze or synthesize, or in any way have to do with the quantitative relations of reacting chemical substances under any circumstances, we must ultimately turn to the atomic weights for help. It is not too much to say that the atomic weights are the basis of quantitative chemistry.

More than two thousand years ago Plato said: "If from any art that which concerns weighing, measuring, and arithmetic is taken away, little remains of that art." To-day we may paraphrase this saying as follows: "If from chemistry are taken away the atomic weights (or other numerical data representing the same definite proportions), little will remain of that science." As a science becomes more scientific it becomes more quantitative, and greater accuracy in the determination of its fundamental mathematical basis is required.

There is not time this afternoon to go into the details of many determinations of nearly thirty atomic weights carried out during as many years at Harvard. The effort was made to build upon the basis provided by the careful work of Berzelius, Marignac, and Stas, with the help of the new discoveries in physical chemistry concerning solubility, hydrolysis, adsorption, and solid solution. Metals were compared, as to their combining proportions, especially with chlorine, bromine, and iodine; moreover, many other careful comparisons likewise were made, as, for example: oxygen with silver through lithium chloride and lithium perchlorate; silver into nitrogen and sulphur through silver nitrate and sulphate; oxygen with carbon and sulphur sodium carbonate and sulphate, and many others. These, taken together, tend to put our whole table of atomic weights upon a stabler basis. The elements of which the atomic weights have been determined under my own immediate supervision are the following: copper, barium, strontium, calcium, magnesium, zinc, nickel, cobalt, iron, uranium, cæsium, sodium, potassium, chlorine, nitrogen, silver, sulphur, carbon, lithium, and radio-lead. To these should be added, as part of the Harvard contribution those studied by my most energetic pupil in this line of work, Prof. G. P. Baxter, long since an independent investigator on his own account: arsenic, bromine,

cadmium, chromium, iodine, lead, meteoric iron and nickel, manganese, neodymium, praseodymium, and phosphorus. The most interesting outcome of my work is perhaps the discovery that lead from radio-active minerals possesses an atomic weight distinctly less than that of ordinary lead—206.1 instead of 207.2—although it gives the same spectrum.

If I were to sum up in a few words the lessons of these protracted investigations, I should be inclined to say that the secret of success in the study of atomic weights lies in carefully choosing the particular substances and processes employed, and in checking every operation by parallel experiments so that every unknown chemical and physical error will gradually be ferreted out of its hiding-place. The most important causes of inaccuracy are: the solubility of precipitates and of the material of containing vessels; the occlusion of foreign substance by solids, and especially the presence of retained moisture in almost everything. Each of these disturbing circumstances varies with each individual case. Far more depends upon the intelligent choice of the conditions of experiment than upon the mechanical execution of the operations, although that, too, is important. I have often quoted the innocent remark which has occasionally been made to me: "What wonderfully fine scales you must have to weigh atoms!" and have endeavored to point out that the purely chemical work, which precedes the introduction of the substance into the balance-case, is much more important than the mere operation of weighing.

Laboratory work alone can furnish us with accurate values of the atomic weights. No speculative method involving higher mathematics has as yet been able to solve definitively the cosmic puzzle of their relative magnitudes. In this direction, as in many others, chemistry is still largely an inductive science. When we have discovered the realities, we shall be in a position to attempt to explain them. In the meantime more accurate views, discovered little by little through patient investigation, will be of use to the thousands of men throughout the world who daily employ these fundamental data of chemistry.

Matter possesses not only the fundamental properties of weight and mass, measured (from the chemical point of view) by the combining proportions of the elements, but also an equally fundamental attribute which causes it to occupy space. Thus, side by side with the study of weight and mass, the study of volume de-

serves close attention. This latter property is more changeable and more puzzling in its varied manifestations than the constant attributes of weight and mass. Almost every solid expands, occupying more space as it is heated, expands yet more in the act of melting, and finally swells up into an altogether disproportionate volume when it is converted into vapor. In each of these states of matter the application of pressure produces a lessening of the volume—very small, but still perceptible in the case of solids, usually greater in the case of liquids, and still very much greater in the case of gases. The behavior of gases is very similar in each case: here the molecules must be far apart. On the other hand, solids and liquids behave in a manner entirely different from gases and entirely different from one another. The molecules must be very near one another, and the specific nature of each must come greatly into play. Even for any single substance the space-filling relations of the solid and liquid form are highly complex, and when comparison is made between different substances the complexity is vastly increased; yet none of these varying manifestations of the property of occupying space can be accidental. Each must have its inner significance, and the relation of each to the other cannot but be fundamentally connected with the ultimate nature of the substance concerned. Some of the relations are opened to us by the science of thermodynamics; but many of the data must be found, like the atomic weights, by experiment alone.

These considerations led me, nearly twenty years ago, to begin the study not only of the space occupied by the elements, especially in their liquid and solid states of aggregation, but also of many other related fundamental properties of the elements and their compounds, including the effect of increasing temperature and increasing pressure. Some of the data needed in this study had already been provided by the preceding work of others, but particularly in the case of compressibility, of which I wish especially to speak, very few data had been gathered even as recently as fifteen years ago. Only three or four elements had been carefully studied, and these by methods of doubtful efficacy. Hence the first step was to devise a simple and accurate method capable of determining the exceedingly small compressibilities of the solid elements. This method was devised in 1903, and with its help the compressibilities of nearly forty elements have been determined with sufficient accuracy to trace with some precision their relations

to one another and to the bulk occupied by these same elements. Bridgman has since carried the determination of a few of these to much higher pressures, with confirming results.

The outcome is highly interesting. If the elements are arranged in the order of their atomic weight, we find that the compressibilities show a very well-marked alternating periodic increase and decrease as the atomic weight progresses. This fluctuation parallels in remarkable fashion the periodicity of the atomic volumes noticed long ago by Lothar Meyer. It appears that when an element has a large atomic volume (that is to say, when the bulk occupied by its atomic weight in grammes is large) the compressibility also is large, and *vice versa;* and the changes are of the same order in the two cases. That these two properties are fundamentally connected no one can doubt after studying the parallel curves showing their similar progression with increasing atomic weight. Neither can one doubt that in the tracing of this parallelism a real step has been made in the study of the nature of the element.

Other properties, more or less related, also have been shown to have analogous rhythms, but lack of time prevents any attempt to explain them.

One may well ask: Can any conceivable interpretation be found for such parallel rhythms, analogous to Dalton's interpretation of the combining weights of the elements? In other words, can we refer effects concerned with the space occupied by gross matter to the atoms themselves, somewhat as the combining proportions of the elements are refered to the weights of the atoms? It seems to me that this can be done.

If one assumes that the practical bulk of the atoms in solids and liquids is compressible, most of these results fit naturally into their expected places. Those atoms which are much distended (that is to say, have large atomic volume) would be expected to be the most compressible. We should expect also to find that increasing chemical affinity, by pulling the atoms more and more together, would likewise cause compression and, therefore, diminish volume; and cohesive affinity would have the same effect. There is much evidence to show that this interpretation is a reasonable one, but time forbids again that the details should be entered into here. The hypothesis is pragmatic; it considers, not the hypothetical space which may or may not be occupied by an imag-

inary centre or core in the atom, but rather the space which the atom actually requires in solids and liquids. That this space is definite and significant is proved beyond cavil by such curves as those to which I have referred, as well as many other facts concerning solids and liquids. One may well hope that the combined following of this trail may lead one to heights from which a broader view of the materials constructing the universe may be obtained. But even if the hypothesis should some time be found wanting, it has served already a purpose helpful to progress, for it has stimulated many researches leading to the acquisition of new facts. These will stand in the future, whatever may be the fate of the theory.

Do these investigations concerning ultimate properties of things and these hypotheses concerning the correlation of the properties seem to be remote from the pressing problems of humanity? Not so. We must remember that applied science follows in the footsteps of theoretical science. The laws of chemistry cannot be adequately applied until they have been discovered. Only by researches delving into the hidden secrets of Nature by some such processes as these can new discoveries in the realm of pure science be made; and no one can tell how great may be the gain to the philosophy of Nature, as well as to the daily lives of men, ultimately resulting from new knowledge thus gained.

The vital importance of chemistry to modern civilization is well known to this distinguished audience. Some one has wisely remarked that, whereas the nineteenth century was primarily devoted to advance in mechanical and electrical directions, the twentieth century bids fair to be an essentially chemical century. In war—now, alas! devastating the earth—as well as in the lasting peace for which we hope, chemistry is bound to play an all-important part. We perceive that every manufacture is concerned with chemical substances; we realize that recent chemical discoveries have revolutionized the preparation of many things essential to our life and have initiated entirely new industries of great importance and benefit to mankind. The great war has only intensified our appreciation of these facts. We recognize also that even we ourselves, so far as our material existence is concerned, are chemical machines, and that our every thought and act is intimately bound up with chemical reactions, without which neither thought nor act could come into being. Let us hope that

the triumphs of chemistry in the future will be used not only for furthering manufacture and agriculture, thereby rendering life more comfortable and prosperous; but also, above all, for advancing hygiene and medicine to a point where the physician will be able really to understand the complex anomalies which confront him every day. Let us hope, too, that with this practical progress may be united the growth of a broader and saner philosophy of Nature, founded upon a truer knowledge of the materials composing the universe and of the energy which animates it. To such ends, full of blessing to humanity, let us dedicate the science in the future.

In introducing Dr. John J. Carty, Dr. Keller said:

"*Mr. President:* In discussions on the teaching of science in our schools and colleges there is often a tendency on the part of educators to underestimate, and even to belittle, the value of applied science. Only a few weeks ago I listened to an entertaining, and in some respects quite illuminating, after-dinner speech in which the applications of scientific knowledge were referred to as "*ephemeral*," while the speaker, an eminent biologist, laid great stress upon the *permanent* value of the results of scientific investigation. Such statements, Mr. President, are apt to lead to conclusions which are quite erroneous, and certainly at variance with the traditions and the beliefs of this venerable Institute, devoted to Science and the Mechanic Arts. While we may readily concede that a new fact or principle, definitely established, is a permanent addition to the sum of human knowledge, and that such a fact or principle may lead to applications that minister to our material needs, we also maintain that these practical applications are no less permanent additions to human progress and civilization. Whilst paying homage to the Faradays and the Hertzes, to the Lavoisiers and the Liebigs, who have made the fundamental discoveries in electricity and chemistry, let us not forget to honor those who by their inventive genius and engineering skill have utilized these discoveries in creating and developing the marvellous industries of the electrical arts and the chemical manufactures. Just as there are fundamental scientific discoveries, so there are also basic inventions in the arts. The printing press that turns out the enormous editions of our daily papers

still embodies the crude but basic device of Gutenberg; and the wonders of the transmission of human speech, which it is our rare good fortune to witness here to-day, would scarcely have been possible without the pioneer work of Alexander Graham Bell and Guglielmo Marconi.

But it is a far cry, an almost inconceivable advance, from the infant invention of 1876, which then enabled Professor Bell to talk to his assistant, Mr. Watson, two miles away, to the vast Bell Telephone System of 1916, which, with its vast network of lines, covers all the States of the Union, and, with the epoch-making wireless extension during the past year, now permits one not only to speak without effort and distinctly across the continent, but to distant islands and continents and to ships at sea. It sounds like a fairy tale, indeed, to be told that messages sent from Arlington by wireless have been heard and the voice of the speaker recognized at Honolulu, nearly five thousand miles away. To tell the story of the marvellous development of the art of telephony here in America, the country of its birth, is to narrate the rise and development of an entirely new science—that of telephone engineering. While a great army of engineers, inventors, financiers, and others have played more or less conspicuous parts in this development and contributed their share to the recorded achievements, the dominating figure in the story is that of him who is now the chief engineer of the American Telephone and Telegraph Company, and who, in recognition of his life's work, is to receive from you, Mr. President, the Franklin Medal.

The story of his life is simple; its great and dramatic events are his scientific achievements and their public recognition. He was born in Cambridge, Mass., in 1861. Circumstances did not permit him to continue his education after his graduation from the Cambridge Latin School. A natural bent for mechanics was doubtless the reason for his seeking employment with the Telephone Dispatch Company of Boston. Thus he entered the telephone business as a boy of eighteen, and during the eight years he remained with this concern he made a number of valuable contributions to the telephone art, among them the construction of a multiple switchboard, at that time the largest ever put in use, and of the first metallic circuit multiple switchboard, of which certain features are retained in all the boards of to-day. In 1887 he was placed in charge of the cable department of the

Western Electric Company in the East, and subsequently of the switchboard department of this company. During these years he made many important improvements in cable laying and manufacture, as well as in the design of switchboards. In 1888 he had perfected a "common battery" system, by which two or more telephone circuits could be operated; and it was from this that the present standard common battery system was evolved.

While thus engaged in the solution of various engineering problems, he also devoted some of his time to scientific research. A paper read by him in 1889, and entitled "A New View of Telephone Induction," called attention to the fact that electrostatic induction is the main factor in producing cross-talk, and that this cross-talk may be prevented by the insertion of a telephone at the "silent" or "neutral" point of the circuit. In a later communication he explained how by twisting and transposing telephone lines they may be rendered free from inductive disturbances.

In 1889 he entered the service of the Metropolitan Telephone and Telegraph Company, now the New York Telephone Company. In this position he accomplished the great tasks of organizing the various technical departments, of building up the staff of the company, and of repeatedly reconstructing and modernizing the entire plant. The extensions he then provided for constitute the present comprehensive telephone system of New York.

In 1887 he was appointed to the position he occupies to-day, that of chief engineer of the American Telephone and Telegraph Company. He thus became responsible for all the engineering work, both of plant and traffic, of the great Bell System, and all the great developments that have since been carried to a successful conclusion were made under his direction.

Among these is the longest underground telephone cable in the world, connecting Boston, New York, and Washington. Until 1912 the steady improvement of the lines and apparatus permitted the extension of the service to Denver, Colo., a distance of 2100 miles from New York City. Three years later, in January, 1915, the dedication to the use of the public of the completed transcontinental telephone circuits from San Francisco to New York and Boston was held, with impressive ceremonies, in the presence of a most distinguished gathering.

With achievements such as these it might be supposed that even the most ambitious of mortals would be content to rest upon

his laurels. Not so with our medallist. On the heels of the completion of the transcontinental telephone circuits came the announcement that this wizard had accomplished and demonstrated what only a few years ago the wildest flights of the scientific imagination would scarcely have suggested as possible. I refer to the transmission of the speaking voice by a wireless telephone to places outside and far beyond the network of the Bell System. This epoch-making achievement, supplementing as it does the wire service, is now well under way to bring about the ultimate goal of telephony—the establishment of a Universal System.

Such, Mr. President, are the services for the benefit of mankind which the master mind of the telephone art has rendered as the results of a lifetime of indefatigable labor, guided by a scientific imagination of the highest order. But a few years ago his name was comparatively unknown outside of his profession, to-day it is one to conjure with in every quarter of the Globe: it is Dr. John J. Carty, Chief Engineer of the American Telephone and Telegraph Company, whom I have the honor to introduce to you as recipient of The Franklin Medal."

The *President,* in presenting the Franklin Medal to Dr. John J. Carty, said: "I have the honor, in the name of The Franklin Institute, as recommended by its Committee on Science and the Arts, and in recognition of your distinguished services to mankind, rendered in the field of science, to present to you the Franklin Medal, the highest honor in the gift of the Institute."

After expressing his appreciation of the honor conferred upon him, Dr. Carty read the following address:

THE TELEPHONE ART.

BY

JOHN J. CARTY, E.D., D.SC.,

Chief Engineer, American Telephone and Telegraph Company.
Member of the Institute.

More than any other, the telephone art is a product of American institutions and reflects the genius of our people. The story of its wonderful development is a story of our own country. It is a story exclusively of American enterprise and American progress, for, although the most powerful governments of Europe

have devoted their energies to the development and operation of telephone systems, great contributions to the art have not been made by any of them. With very few exceptions, the best that is used in telephony everywhere in the world to-day has been contributed by workers here in America.

It is of peculiar interest to recall the fact that the first words ever transmitted by the electric telephone were spoken in a building at Boston, not far from where Benjamin Franklin first saw the light. The telephone, as well as Franklin, was born at Boston, and, like Franklin, its first journey into the world brought it to Philadelphia, where it was exhibited by its inventor, Alexander Graham Bell, at the Centennial Exhibition in 1876, held here to commemorate the first hundred years of our existence as a free and independent nation.

It was a fitting contribution to American progress, representing the highest product of American inventive genius, and a worthy continuance of the labors of Franklin, one of the founders of the science of electricity as well as of the Republic.

Nothing could appeal more to the genius of Franklin than the telephone, for not only have his countrymen built upon it an electrical system of communication of transcendent magnitude and usefulness, but they have made it into a powerful agency for the advancement of civilization, eliminating barriers to speech, binding together our people into one nation, and now reaching out to the uttermost limits of the earth, with the grand aim of some day bringing together the people of all the nations of the earth into one common brotherhood.

On the tenth day of March, 1876, the telephone art was born, when, over a wire extending between two rooms on the top floor of a building in Boston, Alexander Graham Bell spoke to his associate, Thomas A. Watson, saying: "Mr. Watson, please come here; I want you." These words then heard by Mr. Watson in the instrument at his ear constitute the first sentence ever received by the electric telephone. The instrument into which Mr. Bell spoke was a crude apparatus, and the current which it generated was so feeble that, although the line was about a hundred feet in length, the voice heard in the receiver was so faint as to be audible only to such a trained and sensitive ear as that of the young Mr. Watson, and then only when all surrounding noises were excluded.

Following the instructions given by Dr. Bell, Mr. Watson

John J. Carty

with his own hands had constructed the first telephone instruments and ran the first telephone wire. At that time all the knowledge of the telephone art was possessed exclusively by these two men. There was no experience to guide and no tradition to follow. The founders of the telephone, with remarkable foresight, recognized that success depended upon the highest scientific knowledge and technical skill, and at once organized an experimental and research department. They also sought the aid of university professors eminent for their scientific attainments, although at that time there was no university giving the degree of Electrical Engineer or teaching electrical engineering.

From this small beginning there has been developed the present engineering, experimental, and research department which is under my charge. From only two men in 1876, this staff has, in 1915, grown to more than 600 engineers and scientists, including former professors, post-graduate students, and scientific investigators, graduates of nearly a hundred American colleges and universities, thus emphasizing in a special way the American character of the art. The above number includes only those devoted to experimental and research work and engineering development and standardization, and does not include the very much larger body of engineers engaged in manufacturing and in practical field work throughout the United States. Not even the largest and most powerful government telephone and telegraph administration of Europe has a staff to be compared with this. It is in our great universities that anything like it is to be found, but even here we find that it exceeds in number the entire teaching staff of even our largest technical institutions.

A good idea may spring up in the mind of man anywhere, but as applied to such a complex entity as a telephone system, the countless parts of which cover a continent, no individual unaided can bring the idea to a successful conclusion. A comprehensive and effective engineering and scientific and development organization such as this is necessary, and years of expensive work are required before the idea can be rendered useful to the public.

But, vital as they are to its success, the telephone art requires more than engineers and scientists. So we find that in the building and operation and maintenance of that vast continental telephone system which bears the name of Bell, in honor of the great inventor, there are at work each day more than 170,000 employees,

of which nearly 20,000 are engaged in the manufacture of telephones, switchboards, cables, and all of the thousands and tens of thousands of parts required for the operation of the telephone system of America.

The remaining 150,000 are distributed throughout all of the states of the Union. About 80,000 of these are women, largely telephone operators; 50,000 are linemen, installers, cable splicers, and the like, engaged in the building and maintaining of the continental plant. There are thousands of other employees in the accounting, legal, commercial, and other departments. There are 2100 engineers located in different parts of the country. The majority of these engineers have received technical training in American technical schools, colleges, and universities. This number does not include, by any means, all of those in the other departments who have received technical or college training.

In view of the technical and scientific nature of the telephone art, an unusually high-grade personnel is required in all departments, and the amount of unskilled labor employed is relatively very small. No other art calls forth in a higher degree those qualities of initiative, judgment, skill, enterprise, and high character which have in all times distinguished the great achievements of America.

In 1876 the telephone plant of the whole world could be carried away in the arms of one man. It consisted of two crude telephones like the one now before you, connected together by a wire of about one hundred feet in length. A piece cut from this wire by Mr. Watson himself is here in this little glass case.

At this time there was no practical telephone transmitter, no hard-drawn copper wire, no transposed and balanced metallic circuit, no multiple telephone switchboard, or telephone switchboard of any kind, no telephone cable that would work satisfactorily; in fact, there were none of the multitude of parts which now constitute the telephone system.

The first practical telephone line was a copy of the best telegraph line of the day. A line wire was strung on the poles and housetops, using the ground for the return circuit. Electrical disturbances, coming from no one knows where, were picked up by this line. Frequently the disturbances were so loud in the telephone as to destroy conversation. When a second telephone line was strung alongside the first, even though perfectly insulated,

another surprise awaited the telephone pioneer. Conversation carried on over one of these wires could plainly be heard on the other. Another strange thing was discovered. Iron wire was not as good a conductor for the telephone current as it was for the telegraph current. The talking distance, therefore, was limited by the imperfect carrying power of the conductor and by the confusing effect of all sorts of disturbing currents from the atmosphere and from neighboring telephone and telegraph wires.

These and a multitude of other difficulties, constituting problems of the most intricate nature, impeded the progress of the telephone art, but American engineers, by persistent study, incessant experimentation, and the expenditure of immense sums of money have overcome these difficulties. They have created a new art, inventing, developing, and perfecting, making improvements great and small in telephone, transmitter, line, cable, switchboard, and every other piece of apparatus and plant required for the transmission of speech.

As the result of nearly forty years of this unceasing, organized effort, on the 25th of January, 1915, there was dedicated to the service of the American public a transcontinental telephone line, 3600 miles long, joining the Atlantic and the Pacific, and carrying the human voice instantly and distinctly between San Francisco and New York and Philadelphia and Boston. On that day over this line Dr. Bell again talked to Mr. Watson, who was now 3400 miles away. It was a day of romantic triumph for these two men and for their associates and their thousands of successors who have built up the great American telephone art.

The 11th day of February following was another day of triumph for the telephone art as a product of American institutions, for, in the presence of dignitaries of the city and state here at Philadelphia and at San Francisco, the sound of the Liberty Bell, which had not been heard since it tolled for the death of Chief Justice Marshall, was transmitted by telephone over the transcontinental line to San Francisco, where it was plainly heard by all those there assembled. Immediately after this the stirring tones of "The Star-Spangled Banner," played on the bugle at San Francisco, were sent like lightning back across the continent to salute the old bell in Philadelphia.

It had often been pointed out that the words of the tenth verse of the twenty-fifth chapter of Leviticus, added when the bell was

recast in 1753, were peculiarly applicable to the part played by the old bell in 1776. But the words were still more prophetic. The old bell had been silent for nearly eighty years and it was thought forever, but by the use of the telephone a gentle tap, which could be heard through the air only a few feet away, was enough to transmit the tones of the historic relic all the way across the continent from the Atlantic to the Pacific. Thus by the aid of the telephone art, the Liberty Bell was enabled literally to fulfil its destiny and "Proclaim liberty throughout all the land, unto all the inhabitants thereof."

The two telephone instruments of 1876 had become many millions by 1916, and the first telephone line, a hundred feet long, had grown to one of more than three thousand miles in length. This line is but part of the American telephone system of twenty-one million miles of wire, connecting more than nine million telephone stations located everywhere throughout the United States, and giving telephone service to one hundred million people. Universal telephone service throughout the length and breadth of our land, that grand objective of Theodore N. Vail, has been attained.

While Alexander Graham Bell was the first to transmit the tones of the human voice over a wire by electricity, he was also the first to transmit the tones of the human voice by the wireless telephone, for, in 1880, he spoke along a beam of light to a point a considerable distance away. While the method then used is different from that now in vogue, the medium employed for the transmission is the same—the ether, that mysterious, invisible, imponderable wave conductor which permeates all creation.

While many great advances in the wireless art were made by Marconi and many other scientists in America and elsewhere, it remained for that distinguished group of American scientists and engineers, working under my charge, to be the first to transmit the tones of the human voice in the form of intelligible speech across the Atlantic Ocean. This great event and those immediately preceding it are so fresh in the public mind that I will make but a brief reference to them here.

On April 4th, 1915, we were successful in transmitting speech without the use of wires from our radio station at Montauk Point, on Long Island, to Wilmington, Delaware.

On May 18 we talked by radio telephone from our station on

Long Island to St. Simon Island, in the Atlantic Ocean, off the coast of Georgia.

On the 27th of August, with our apparatus installed by permission of the Navy Department at the Arlington, Virginia, radio station, speech was successfully transmitted from that station to the Navy wireless station equipped with our receiving apparatus at the Isthmus of Panama.

On September 29 speech was successfully transmitted by wire from New York City to the radio station at Arlington, Virginia, and thence by wireless telephone across the continent to the radio station at Mare Island Navy Yard, California, where I heard and understood the words of Mr. Theodore N. Vail speaking to me from the telephone on his desk at New York.

On the next morning, at about one o'clock, Washington time, we established wireless telephone communication between Arlington, Virginia, and Pearl Harbor, in the Hawaiian Islands, where an engineer of our staff, together with the United States Naval officers, distinctly heard words spoken into the telephone at Arlington, Virginia. On October 22, from the Arlington tower in Virginia, we successfully transmitted speech across the Atlantic Ocean to the Eiffel Tower at Paris, where two of our engineers, in company with French military officers, heard and understood the words spoken at Arlington.

On the same day when speech was being transmitted by the apparatus at Arlington to our engineers and to the French military officers at the Eiffel Tower in Paris our telephone engineer at Pearl Harbor, Hawaii, together with an officer of the United States Navy, heard the words spoken from Arlington to Paris and recognized the voice of the speaker.

As a result of exhaustive researches too extensive to describe here, it has been ascertained that the function of the wireless telephone is not to do away with the use of wires, but rather to be employed in situations where wires are not available or practicable, such as between ship and ship, and ship and shore, and across large bodies of water. The ether is a universal conductor for wireless telephone and telegraph impulses and must be used in common by all who wish to employ those agencies of communication. In the case of the wireless telegraph the number of messages which may be sent simultaneously is much restricted. In the case of the wireless telephone, owing to the thousands of separate

wave-lengths required for the transmission of speech, the number of telephone conversations which may be carried on at the same time is still further restricted, and is so small that all who can employ wires will find it necessary to do so, leaving the ether available for those who have no other means of communication. This quality of the ether which thus restricts its use is really a characteristic of the greatest value to mankind, for it forms a universal party line, so to speak, connecting together all creation, so that anybody, anywhere, who connects with it in the proper manner, may be heard by every one else so connected. Thus a sinking ship or a human being anywhere can send forth a cry for help which may be heard and answered.

No one can tell how far away are the limits of the telephone art. I am certain that they are not to be found here upon the earth, for I firmly believe in the fulfilment of that prophetic aspiration expressed by Theodore N. Vail, at a great gathering in Washington, that some day we will build up a world telephone system, making necessary to all peoples the use of a common language or a common understanding of languages which will join all of the people of the earth into one brotherhood. I believe that the time will come when the historic bell which now rests in Independence Hall will again be sounded, and that by means of the telephone art, which to-day has received such distinguished recognition at your hands, it will proclaim liberty once more, but this time throughout the whole world, unto all the inhabitants thereof. And, when this world is ready for the message, I believe the telephone art will provide the means for transmitting to all mankind a great voice saying, " Peace on earth, good-will toward men."

PRESENTATION OF THE ELLIOTT CRESSON MEDAL TO THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY, THROUGH MR. THEODORE NEWTON VAIL, PRESIDENT.

In introducing Mr. Theodore N. Vail Dr. Keller said:

" *Mr. President:* In awarding the Franklin Medal to Dr. John J. Carty The Franklin Institute is fully aware that the marvellous achievements of this pioneer and leader in the science of telephone engineering are shared in a large measure by the corporation of which he is the chief engineer, by the men who have developed

and directed this vast business enterprise and made the Bell System what it is to-day, and by that wonderfully efficient technical staff which Doctor Carty has created and trained. In recognition of this fact, the Committee on Science and the Arts has unanimously recommended that the Elliott Cresson Medal of the Institute, the highest distinction it can confer upon a corporation, be awarded to the American Telephone and Telegraph Company for its constructive and far-seeing policy in the development of the art of telephony, in the promotion of telephone engineering, in the establishment of its telephone system in every part of the United States, and for placing all of the States of the Union in speaking communication.

To indicate the vast extent of the Bell System I may be permitted to quote a few statements from an address made by Mr. Bethell, senior vice-president of the American Telephone and Telegraph Company, at the formal opening of the transcontinental line, a little more than a year ago. The plant of the company and its associated companies then represented an investment of $850,000,000. Joining together more than 70,000 communities, it transmitted over its lines about nine billions of messages a year, or 26,000,000 a day. Exclusive of the associated companies, it employed an army of 160,000 men and women. More than twice as much has been spent upon the improvement and extension of the Bell System during the time the Panama Canal was being constructed as the entire cost of this great undertaking.

Such figures are simply staggering, and we can only marvel at the vastness of this system of communication which reaches every part of our country, and triumphantly proclaims man's conquest over space and time. With a feeling akin to awe we think of the man whose prophetic vision, unerring judgment, and matchless executive ability have guided the forces which have wrought this wondrous evolution. He comes of sturdy old Quaker stock, and some of his forbears have greatly distinguished themselves as engineers and electricians. During the early years of his career he was employed in the railway mail service, in which his pronounced ability to systematize and organize secured him rapid promotion. As general superintendent he brought the railway mail service to a state of high efficiency and did much to promote the Civil Service system. But it was with his appointment as general manager of the American Bell Telephone Company, in

1878, that he entered a field commensurate with his abilities. In spite of innumerable obstacles he succeeded in developing the invention of Alexander Graham Bell into a commercial success, and he soon realized that it had possibilities far beyond mere local service. From his first achievement in long-distance telephony—the line connecting Boston and Providence—his dominant spirit has continued to secure improvements in telephone material and construction until to-day the lines span the distance from the Atlantic to the Pacific. As president of the American Telephone and Telegraph Company he has effected the financial and technical organization of this vast corporation, and nothing could be more appropriate on this occasion than his receiving from your hands the Elliott Cresson Medal awarded to his company. Mr. President, I deem it a very great honor to present to you Mr. Theodore Newton Vail, president of the American Telephone and Telegraph Company."

The *President,* in presenting the Elliott Cresson Medal to Mr. Vail, for the American Telephone and Telegraph Company, said: "I have the honor, in the name of The Franklin Institute, as recommended by its Committee on Science and the Arts, and in recognition of the great work performed by the American Telephone and Telegraph Company in the development and perfecting of the art of speech transmission, to present to you for that company the Elliott Cresson Medal, the highest honor to a corporation in the gift of the Institute." In accepting this recognition for the American Telephone and Telegraph Company, Mr. Vail addressed the Institute as follows:

ADDRESS

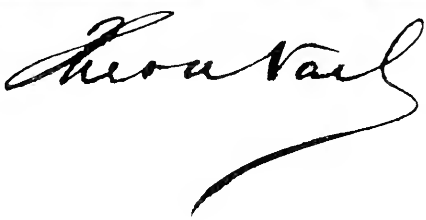
BY

MR. THEODORE N. VAIL,

President American Telephone and Telegraph Company.

"*Mr. President and Members of the Institute, Ladies and Gentlemen:* On behalf of the American Telephone and Telegraph Company I accept this most complimentary tribute.

When the telephone business was first organized, the possibility, but not the magnitude, of the future was recognized. Then was adopted, after deliberation and discussion by the founders of the business, the comprehensive policy of making the telephone a useful utility, broad in its scope and universal in its application.



This policy has been faithfully followed by those who have been responsible for the operations of the business.

We accept this tribute of to-day as a recognition by this great Institute and by the public that that policy was a wise one, and that it had been wisely and successfully carried out.

This tribute has another and even greater significance.

The telephone service is an individual service, rendered to individual users by the individual members of the telephone organization.

It is a service dependent upon the right thing being done at the right time, by the right person, in the right way. To the extent that all this is done the service is good; if any fail, to that extent the service is defective.

This requires on the part of every individual member: to the organization, loyalty; to their obligations, fidelity; and in the performance of their duty, conscientiousness.

This award is, therefore, a personal tribute to each individual connected with the service, to the full recognition, by them, of their obligation to the organization and to the public, and each one will so feel and appropriate it.

Gentlemen, on behalf of my company and on behalf of my associates, on behalf of every individual connected with the Bell System, please accept hearty thanks and expressions of the highest appreciation of your action."

Following Mr. Vail's address, the American Telephone and Telegraph gave an interesting demonstration of transcontinental and wireless telephony, which was repeated at intervals during the evening for the benefit of the Institute's membership and friends.

From Engine to Axle. B. W. SHILSON. (*Proceedings of the Institution of Automobile Engineers*, April, 1916.)—This paper is intended to form a link between those recently read before the Institution by Messrs. W. D. Williamson on "Engines" and G. W. Watson on "Live Axles," and deals with clutches, change speed boxes, and universal joints.

The earliest form of clutch, namely, the metal-to-metal cone clutch, has now fallen into disuse in favor of the leather cone type, and this in its turn has been almost entirely replaced by a cone lined with a bonded asbestos surface having a higher coefficient of friction and no tendency to burn. The trouble with the metal-to-metal type was, of course, its suddenness of action, and, with the leather-to-

metal type, the burning up of the leather. But experience has shown that if the angle of the cone is not less than 15 degrees the specific pressure does not exceed 7 pounds per square inch, and if the leather is well lubricated it can run with satisfaction for long periods, as shown in the case of London 'bus work. In order to keep the leather in good condition, the Mandslay Company fixes a shield to the flywheel so that the cone is always immersed in oil. In America cork inserts have been used as a friction surface, but this form of clutch has not been widely adopted on account of the uncertainty of its action.

The introduction of the multiple disk type brought troubles of its own, resulting from the dragging of the clutch and consequent gear-changing difficulties, owing to the fact that this clutch must be run in oil and the plates when pressed together drive out the air, so that they are held together by atmospheric pressure when the clutch spring is released. In the author's opinion, the most satisfactory type of clutch is a single plate held between one face of the flywheel and an axially sliding ring.

Generally speaking, the change-speed boxes in use at the present time are either of the spur or silent chain types. The small number of epicyclic gear boxes on the market are chiefly of American design. The introduction of ball bearings was found to greatly increase the noise transmitted. There is, however, a type of ball bearing in the market in which the ball cage consists of two sections of die-cast with metal, so cast as to give surface support instead of line contact, and this was found to eliminate to a large extent the noise due to spinning. A feature of ball bearing frequently overlooked by the designer is the gradual settling of the bearing into the soft aluminum housing. It is recommended that these be housed in malleable iron covers or in a separate steel sleeve. Rigidity is of the greatest importance, and this end should be kept constantly in view in designing a gear box. Square shafts have been almost entirely replaced by broached castellated shafts.

On most vehicles a high-speed brake is fitted at the back of the gear box. This can be of the internal expanding or the external contracting type, common practice favoring the latter. The best braking surface is bonded asbestos or a good quality of cast iron. Adjustment in the length of the propeller shaft to allow for the rise and fall of the axle relative to the frame is most conveniently taken up by a sliding castellated shaft. The universal joints, owing to their position on the chassis, are always liable to neglect, and great care should be taken in their lubrication. One thousand pounds per square inch has been found a satisfactory specific pin pressure. For extreme conditions of service there is no doubt that the most satisfactory joint is that in which ball bearings are mounted on the pins of the universal joint forks.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A STUDY OF THE INDUCTANCE OF FOUR-TERMINAL RESISTANCE STANDARDS.[1]

By Francis B. Silsbee.

[ABSTRACT.]

THE precise measurement of alternating currents frequently involves the use of standard resistances the inductance of which should be known. When the currents are large the standards used are usually of low resistance, and a very small inductance in such a standard may produce a very considerable phase angle between the voltage drop across the resistance and the current. In the range below one ohm the resistances are almost invariably of the four-terminal type and therefore require methods of measurement which are quite distinct from those applicable to higher resistances. The object of this investigation was to develop methods for comparing the phase angles of such four-terminal resistances and also to construct standards, having a very small known inductance, with which other apparatus could be compared.

If we consider a four-terminal resistance (or, more briefly, a "shunt") which carries a sinusoidal alternating current, we will find that the voltage between the potential terminals is not in general in phase with the current, but may be resolved into two components, one in phase and one in quadrature. The resistance of the shunt is defined as the ratio of the in-phase component to the current, while the reactance is the ratio of the quadrature component of voltage to the current. The angle whose tangent is ratio of reactance to resistance is the phase angle of the shunt. The inductance is, of course, equal to the reactance divided by 2π times the frequency, while the time-constant is the ratio of the inductance to the resistance. This latter quantity is very nearly constant over the range of commercial frequencies and is a measure of the amount by which a shunt departs from the ideal condition of giving a voltage exactly in phase with the current.

In some of the measurements described below it was necessary to use mutual inductances, and it was found that these did not in general satisfy the ideal condition of giving a secondary voltage in exact quadrature with the primary current, but that the voltage

* Communicated by the Director.

[1] Scientific Paper No. 281.

had a small in-phase component. By analogy with the case of the shunt we may define the " resistance " of the mutual inductance as the ratio of this in-phase component of voltage to the primary current. We will further define the " phase defect " as the angle whose tangent is the ratio of the in-phase component of voltage to the quadrature component.

The method for the comparison of the time constants of two shunts which was found most suitable may be called the Current Transformer Method. It consists essentially of measuring the apparent phase angle of a current transformer by one of the usual null methods, using in succession, as the standard resistance in the primary circuit of the transformer, the two shunts to be compared. The apparent change in the phase angle of the transformer is the difference in the phase angle of the two shunts. A group of about twenty shunts were intercompared by this method and form a basis for future comparisons. A second method involving the use of mutual inductances was tried out, and gave results in agreement with the first method, but was found to be much less convenient.

Since the comparison methods just mentioned give only the difference in time-constant of two four-terminal standards, some other measurement is needed to give the actual value of the time-constant of one four-terminal shunt in terms of known quantities. The simplest way to obtain this value is to construct a shunt of such shape that the inductance can be computed from the measured dimensions. This procedure requires that certain assumptions be made as to current distribution, etc., but a careful investigation using three different shapes of shunt showed that these assumptions were completely justified. As a check two other methods of measurement were tried, one involving the use of mutual inductances of known phase defect, and the other using two shunts constructed of identical dimensions, but of materials of different resistivities. These methods gave results in agreement with the computed values, but were less accurate and more laborious. It is believed that the time-constants of the group of shunts, ranging from 0.1 ohm to 0.00025 ohm, at the Bureau of Standards are known to an accuracy of 1 or 2×10^{-7} seconds. With a frequency of 60 cycles and an uncertainty of 2×10^{-7} seconds in the time-constant, the phase angle between the voltage and current is uncertain by about 15 seconds of arc.

Further measurements were made on other types of shunt and also on the effect of stray magnetic fields on the apparent time-constants of the shunts.

In the design of shunts for use on alternating current it appears that the liability to error can be minimized by so locating the potential leads that the inductive effects in them completely neutralize the inductance of the resistance material itself and the shunt as a whole is strictly non-inductive. The type in which the resistance material forms one or both of two concentric tubes lends itself very readily to this form of compensation.

A study of the phase defects of mutual inductances of large current capacity showed that this source of error was by no means negligible, and that it was particularly large in cases where the secondary was wound in several layers.

A more complete account of this investigation is to be published shortly in the *Bulletin of the Bureau of Standards.*

SENSITIVITY AND MAGNETIC SHIELDING TESTS OF A THOMPSON GALVANOMETER FOR USE IN RADIOMETRY.*

By W. W. Coblentz.

The present paper gives the results of an investigation of the force exerted by various galvanometer coils when operated under standard conditions. Some of the coils were wound according to theoretical requirements, while others were wound empirically. Numerical data are given relating to coils having various resistances.

A simple coil is described, wound with a single size of wire (x 28 B. & S.), which is as efficient as a compound coil wound in three sections of graded wire upon the same mandrel.

A 9-ohm coil of graded wire is described which is very efficient and is well adapted to be used with the bismuth-silver thermopiles previously described.

A comparison is made of various astatic magnet systems and data are given showing the importance of using small mirrors, in order to increase the sensitivity.

Experiments are described on shielding the galvanometer from external magnetic disturbances. The galvanometer coils are

* Scientific Paper No. 282.

mounted in cavities cut into blocks of Swedish iron which reduce the air space and act as a magnetic shield. This elimination of convection currents greatly improves the steadiness of the needle system. Various shields are described, consisting of laminated cylinders made from transformer iron, and solid cylindrical shells cut from wrought-iron gas pipe. By imbedding the galvanometer coils in blocks of Swedish iron which are surrounded by cylindrical shells of transformer iron and of wrought iron the effect of external magnetic perturbations upon the astatic needle system is easily reduced to one two-thousandth of its original value.

Experiments on a vacuum galvanometer are described in which a sensitivity was attained which is more than ten-fold that used in the writer's previous work on stellar radiation.

THE VOLUME EFFECT IN THE SILVER VOLTAMETER.*

By E. B. Rosa and G. W. Vinal.

SOME years ago the Bureau discovered that the silver deposits in large-size voltameters were consistently heavier than the deposits in small voltameters which were used in series with them. The cause of this effect was attributed to impurities in the solution, but this explanation was not accepted by all the observers who have worked with the voltameter. Jaeger and von Steinwehr thought that because the evidence rested principally on the results with the porous-cup form of voltameter the effect was due to the porous cup. Richards, on the contrary, thought that the greater surface of the large cathodes permitted greater inclusions and therefore the deposit appeared heavier. The recent experiments of Vinal and Bovard have shown that Richards's theory is not correct, but some further experiments were necessary to answer Jaeger and von Steinwehr's contention.

The authors have analyzed all of their former observations with reference to the volume of the electrolyte, the weight of the deposit, and the purity of the solution. They have also made some further experiments with especially impure solutions and with other forms of the voltameter than the porous-cup form. All of these observations have been treated by statistical methods, and the authors show, first, that the volume effect is not confined to the porous-cup form of voltameter, but that it is common to all

* Scientific Paper No. 283.

forms of voltameter, and, second, that it is caused by impurities in the electrolyte. The authors give a theory for the mechanism of the effect, and they believe that the evidence proves conclusively that it is a valuable criterion for the purity of the silver nitrate.

CONSTANTS OF SPECTRAL RADIATION OF A UNIFORMLY HEATED INCLOSURE OR SO-CALLED BLACK BODY. II.*

By W. W. Coblentz.

A knowledge of the exact value of the constants which enter into the mathematical equation which represents the distribution of energy in the spectrum of a black body is necessary in many physical problems, especially in extending the temperature scale higher than is possible with thermocouples.

The spectral energy curves were obtained by means of a vacuum bolometer, a mirror spectrometer, and a fluorite prism.

The present paper gives the result of a recomputation of the constants of spectral radiation of a black body, which had been published in a previous paper. This recomputation was necessitated as the result of the adoption of a new and apparently more reliable calibration curve of the fluorite prism used in the work, and as a result of the discovery of a small error which was found in the previous computations. Although these errors are small (and would have been considered negligible four years ago), they happen to be of the same sign and hence have an appreciable effect upon the final result.

The results of the present computations give a mean value of $C = 14369$, which is close to the mean value of all the published data.

The data of other investigators are summarized, and it is found that they lie close to $C = 14350$.

From a consideration of the data now available it appears that the values of the constants of spectral radiation are close to

$$C = 14350 \text{ micron deg.}$$
$$A = 2890 \text{ micron deg.}$$

and that the coefficient of total radiation is of the order of $\delta = 5.7 \times 10^{-12}$ watt cm.$^{-2}$ deg^{-4}. This indicates that the constant h of the quantum theory is of the order $h = 6.56$ to 6.57×10^{-27} erg sec.

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* Scientific Paper No. 284.

DETERMINATION OF ALUMINIUM AS OXIDE.*

By William Blum.

[ABSTRACT.]

From observations made with a hydrogen electrode and with suitable indicators, it was found that the precipitation of aluminium hydroxide by ammonium hydroxide is complete when $[H^+] = 10^{-6.5}$ to $10^{-7.5}$, points which are approximately defined by the color changes of methyl red and rosolic acid. From a study of the various factors, the following conditions are recommended for the determination of aluminium. To the solution containing 5 gms. of ammonium chloride per 200 c.c. of solution (or an equivalent amount of hydrochloric acid) add a few drops of methyl red (0.2 per cent. alcoholic solution), and heat the solution just to boiling. Carefully add dilute ammonium hydroxide dropwise, till the color of the solution changes to a distinct yellow. Boil the solution for one or two minutes, and filter. Wash the precipitate thoroughly with hot 2 per cent. ammonium chloride or nitrate solution. Ignite in a platinum crucible, and after the carbon is all burned off, blast for five minutes, cover the crucible and place it in a desiccator till cool. Weigh (covered) as rapidly as possible. A second blasting of five minutes is desirable to facilitate rapid weighing, and consequently probably more accurate results.

THE INFLUENCE OF FREQUENCY OF ALTERNATING OR INFREQUENTLY REVERSED CURRENT ON ELECTROLYTIC CORROSION.†

By Burton McCollum and G. H. Ahlborn.

[ABSTRACT.]

This paper describes experimental work done to determine the coefficient of corrosion of iron and lead in soil with varying frequencies of alternating or reversed current, with 60 cycles per second as the highest frequency and a two-week period as lowest—some direct-current tests being made also as a check on the conditions. It is shown by these experiments that the corrosion of both iron and lead electrodes decreases with increasing frequency of reversal of the current, the corrosion being practically negligible

* Scientific Paper No. 286.

† Technologic Paper No. 72.

for both metals when the period of the cycle is not greater than a few minutes.

With iron electrodes a limiting frequency is reached between 15 and 60 cycles per second, beyond which no appreciable corrosion occurs. No such limit was reached in the lead tests, although it probably exists at a higher frequency than 60 cycles. It was shown that with periodically reversed currents the addition of sodium carbonate to the soil reduces the loss in the case of iron and increases it in the case of lead.

The coefficient of corrosion of lead under the soil conditions described in the report when subjected to the action of direct current was found to be only about 25 per cent. of the theoretical value; whereas the corrosion of iron was found to agree quite closely with the theoretical corrosion.

The corrosion of lead reaches practically its maximum value with a frequency of reversal lying between one day and one week; whereas the corrosion of iron does not reach a maximum value until the period of the cycle is considerably in excess of two weeks.

The most important conclusions to be drawn from the investigations is that in the the so-called neutral zone of street railway networks, where the pipes continually reverse in polarity, the damage is much less than would be expected from a consideration of the arithmetical average of the current discharge from the pipes into the earth. Where pipes are alternately positive and negative with periods not exceeding 10 or 15 minutes, the algebraic sum of the current discharged is more nearly a correct index to the total damage that will result than any other figure that can readily be obtained.

The reduction in corrosion due to periodically reversed currents appears to be due to the fact that the corrosive process is in a large degree reversible; so that the metal corroded during the half cycle when current is being discharged is in large measure redeposited during the succeeding half cycle when the current flows toward the metal. This redeposited metal may not be of much value mechanically, but it serves as an anode surface during the next succeeding half cycle, and thus protects the uncorroded metal beneath.

The extent to which the corrosive process is reversible depends upon the freedom with which the electrolyte circulates, and, particularly, on the freedom of access of such substances as oxygen

or carbon dioxide, which may result in secondary reactions giving rise to insoluble precipitates of the corroded metal. It is largely for this reason that the corrosion becomes greater with a longer period of the cycle, since the longer the period the greater will be the effect of these secondary reactions.

THE DETERMINATION OF VOLATILE THINNER IN OIL VARNISH.*

By E. W. Boughton.

[Abstract.]

Two samples of varnish containing turpentine and two containing "mineral spirits" (light petroleum oil) were used in the investigation. It was found that any of the following methods gave results which were sufficiently accurate for practical purposes: (1) Steam distillation, the still being heated to 115° to 120° C. and the volatile thinner in the distillate separated from the condensed water and weighed. (2) Evaporation of the volatile thinner by heating a thin film of the varnish at 110° to 115° C. in an air-bath, the loss being assumed to be volatile thinner. (3) Brown's method:[1] A weighed portion of the varnish is diluted with a suitable volatile solvent, such as ether or chloroform, to a definite volume. An aliquot portion of this solution is flowed on a weighed glass plate, and the volatile thinner and added solvent allowed to evaporate at room temperature in air or in a current of illuminating gas. The percentage of residue subtracted from 100 per cent. is assumed to be percentage of volatile thinner. (4) Evaporation at room temperature of the volatile thinner from a film of varnish brushed out on a weighed glass plate. In all four of these methods the results for percentage of volatile thinner should be reported as the whole percentage next above the figure obtained.

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* Technologic Paper No. 76.

[1] *Proc. Amer. Soc. for Testing Mat.*, 14, 467 (1914).

NOTES FROM THE NELA RESEARCH LABORATORY.*

THE ABSENCE OF THE PURKINJE PHENOMENON IN THE FOVEA.

By Leonard T. Troland.

Careful experiments by many observers have indicated that the Purkinje phenomenon cannot be obtained if the compared visual stimuli (*e.g.*, a red and a blue light) are confined to the central rod-free area of the retina. Recently,[1] however, Hering has claimed that a very fugitive Purkinje effect can be observed during the first moments of stimulation of the fovea of a dark-adapted eye. Since the conditions under which Hering's experiments were performed do not appear to have been favorable to accurate limitation of the stimulation of the fovea, and on account of the great theoretical importance of the question, it seemed worth while to repeat the work, using an improved method.

Hering employed a field 2.08 degrees in diameter, one half of which was filled with spectral blue light and the other with red. The experiment was carried out by extinguishing the blue, then suddenly fixating the red and at the same instant turning on the blue. Three defects can be pointed out in this method: (1) The field size is too great; (2) local minuthesis ("fatigue") of the red sensation can occur before the blue stimulus becomes effective; (3) steady fixation would be very difficult to obtain at the critical instant, by this method.

In the writer's experiments a field of one degree diameter was employed. This was crossed by a central red belt, 0.34 degree wide, made up of light of wave-lengths, 654–687 $\mu\mu$. The two equal polar segments were filled with blue light of wave-lengths, 469–481 $\mu\mu$. The whole was viewed against a dark background, through an artifical pupil of 1.36 mm. diameter. In the centre of the field was placed a luminous fixation point of 0.060 degree diameter, the brightness of which was just sufficient to make it visible to the dark-adapted eye.

The subject was given five minutes' bright adaptation out-of-doors, in the late morning or early afternoon, with a clear sky and May sun. He was then immediately required to adjust the

* Communicated by the Director.

[1] *Arch. f. Ophthalmol.*, 1915, 90, 1–13.

relative intensities of the red and blue components of the test field so that either (1) the red was slightly but distinctly brighter than the blue, or (2) the two were of equal brightness. The intensity of the blue during this setting was 50 photons (see footnote to next article). The subject was now given 30 minutes' complete dark adaptation, after which he was required to fixate carefully the luminous point. Immediately upon establishment of fixation the original field was suddenly exposed to view, with the first selected relative intensities accurately maintained, but with a reduction of the absolute intensity of both components to one thirty-second of the value at which the bright-adaptation setting was made. This reduction was accomplished by means of a sector disk. Ten successive brief exposures of the field were made in this way, with a minute's rest between, and the subject was asked to judge whether, at the first instant of visibility of the field, the blue was brighter than the red (the Purkinje change).

In four separate experiments of this sort the writer found it impossible to detect the slightest trace of a Purkinje effect when fixation was accurately maintained. Peripheral fixation gave a vivid enhancement of the blue. Observations by two inexperienced subjects under the same conditions yielded conflicting results, which are to be attributed to their inability to fixate accurately. The experiment was also tried by the writer with an initial intensity of 31 photons, and 20 minutes' bright adaptation, with similarly negative results.

June 18, 1916.

THE HETEROCHROMATIC BRIGHTNESS DISCRIMINATION THRESHOLD.

By Leonard T. Troland.

THE measurements described below were made to study some of the principles underlying the "direct comparison" method of heterochromatic photometry.

Although it is always difficult to make a positive judgment that two stimuli of different color are of *equal* brightness, a ratio of intensities can easily be established for which a perfectly secure judgment of *inequality* of brightness can be delivered. Consequently, for any pair of colors it is possible to determine the *brightness discrimination threshold*, and this should be a function

of the colors, or of the difference between them. In the present investigation four standard spectral stimuli were chosen, of mean wave-lengths, 693, 575, 505, 475 $\mu\mu$, respectively, representing as nearly as possible the four psychological primaries. These were compared with each other and with nine additional colors taken at intervals of 30 $\mu\mu$ across the spectrum. The wave-length ranges of the stimuli varied from 4 to 30 $\mu\mu$, according to the position in the spectrum.

The comparison field was viewed against a dark background, and consisted of four vertically juxtaposed, rectangular areas, with a common horizontal dimension of 1.02 degrees. The upper rectangle was filled with the standard color, and the lower rectangle with the comparison color, the height of each of these areas being 0.97 degree. Between them were two bands, of height 0.34 degree each, the upper of which was filled with the comparison colors and the lower with the standard. In making the judgments, attention was directed primarily to these bands.

To determine the threshold values the "method of limits" was employed, the "standard" being subjected to variation in intensity. The relative intensities were found at which the standard was (*a*) just noticeably brighter, (*b*) just not noticeably brighter, (*c*) just noticeably darker, and (*d*) just not noticeably darker, than the comparison field. The fractional threshold values were calculated by means of the formula: $\Delta I = (I - \sqrt{IJ})/I$, where $I = \sqrt{ab}$ and $J = \sqrt{cd}$, if *a*, *b*, *c*, and *d* represent, respectively, the intensities just mentioned, enumerated. This formula is based on Weber's law.

The comparison color was held at a constant intensity which was, in all cases, approximately 25 photons,[1] a square artificial pupil 2.51 mm. on a side being used. The intensity of the comparison color was established by flicker photometry. The general conditions of observation were made, as nearly as possible, the same as those of ordinary photometric work.

The final results for two subjects, T (experienced) and L (inexperienced) are given in the following table. ΔI is the fractional threshold; v is average of the mean variations of the four intensities, *a*, *b*, *c*, *and d*; $\Delta I/S$ is expressed as fractions of these

[1] One photon is an illumination of the retina corresponding with a stimulus-surface brightness of one candle per square metre, and an effective pupillary area of one square millimetre.

intensities; $\Delta I/S$ is the threshold in terms of the homochromatic threshold as a unit; and $\Delta I/v$ is the ratio between the threshold and the average mean variation of its determining points. Each value for subject T (the writer) represents from 40 to 100 independent observations, and for subject L, 20 observations.

Standard Color	Comparison Color, $\mu\mu$.												
Red, 693$\mu\mu$	693	670	640	610	580	575	550	520	505	490	475	460	43
ΔI (T)	.042	.080	.092	.149	.170	.194	.185	.190	.214	.191	.195	.191	.172
(L)	.047	.076	.085	.111	.122	.135	.135	.161	.144	.139	.199	.154	.126
v (T)	.014	.024	.028	.041	.049	.052	.045	.037	.040	.044	.062	.036	.048
(L)	.016	.020	.024	.027	.030	.032	.045	.046	.026	.044	.028	.042	.045
$\Delta I/S$ (T)	1.00	1.93	2.22	3.58	4.09	4.65	4.44	4.5[illegible]	5.15	4.58	4.68	4.60	4.20
(L)	1.00	1.59	1.79	2.33	2.57	2.85	2.85	3.41	3.04	2.94	4.21	3.26	2.58
$\Delta I/v$ (T)	2.99	2.94	3.35	3.64	3.49	3.73	4.10	5.08	4.99	3.88	3.14	4.97	3.26
(L)	2.89	3.70	3.51	4.09	4.08	4.27	2.97	3.49	5.47	3.20	7.12	3.65	2.70
Yellow, 575$\mu\mu$													
ΔI (T)	.150	.169	.175	.155	.097	.037	.125	.126	.185	.161	.201	.191	.169
(L)	.199	.156	.144	.104	.052	.028	.080	.125	.148	.196	.147	.156	.109
v (T)	.038	.031	.041	.043	.023	.010	.035	.026	.041	.057	.042	.032	.046
(L)	.066	.047	.039	.040	.013	.008	.029	.037	.030	.039	.060	.043	.026
$\Delta I/S$ (T)	4.07	4.57	4.75	4.20	2.64	1.00	3.40	3.43	5.00	4.37	5.45	4.97	4.54
(L)	7.22	5.67	5.23	3.76	1.91	1.00	2.91	4.55	5.38	7.12	5.36	5.66	3.90
$\Delta I/v$ (T)	3.93	5.38	4.25	3.58	4.25	3.78	3.54	4.88	4.46	2.75	4.79	6.33	3.66
(L)	2.84	3.29	2.72	2.59	3.97	3.65	2.80	3.40	4.88	5.00	2.47	3.65	4.13
Green, 505$\mu\mu$													
ΔI (T)	.192	.172	.155	.153	.160	.173	.144	.122	.037	.116	.159	.147	.145
(L)	.231	.213	.206	.184	.172	.103	.117	.055	.024	.079	.072	.149	.107
v (T)	.044	.039	.041	.038	.030	.044	.029	.029	.009	.028	.032	.035	.036
(L)	.037	.026	.028	.046	.040	.033	.035	.019	.004	.024	.019	.038	.042
$\Delta I/S$ (T)	5.22	4.69	4.23	4.16	4.35	4.71	3.91	3.32	1.00	3.17	4.33	3.99	3.97
(L)	9.73	9.00	8.69	7.75	7.24	4.54	4.93	2.31	1.00	3.32	3.04	6.28	4.52
$\Delta I/v$ (T)	4.36	4.39	3.76	4.02	4.15	3.96	4.89	4.25	3.88	4.15	4.93	4.18	4.06
(L)	6.28	8.23	7.30	4.04	4.30	3.08	3.38	2.83	6.64	3.33	2.77	3.91	2.55
Blue, 475$\mu\mu$													
ΔI (T)	.173	.176	.178	.131	.128	.118	.129	.129	.126	.121	.075	.174	.181
(L)	.164	.178	.183	.157	.095	.141	.103	.100	.134	.067	.062	.080	.104
v (T)	.039	.060	.053	.034	.046	.030	.036	.046	.056	.033	.013	.045	.029
(L)	.059	.030	.046	.028	.027	.030	.018	.025	.062	.010	.013	.023	.027
$\Delta I/S$ (T)	2.31	2.35	2.38	1.75	1.71	1.58	1.72	1.72	1.68	1.62	1.00	2.32	2.42
(L)	2.66	2.88	2.97	2.54	1.55	2.27	1.67	1.62	2.17	1.08	1.00	1.31	1.68
$\Delta I/v$ (T)	4.45	2.94	3.35	3.89	2.47	3.98	2.96	2.82	2.24	3.72	5.58	3.87	6.30
(L)	2.80	5.91	4.02	5.63	3.49	4.73	5.65	4.01	2.16	6.95	4.91	3.42	3.91

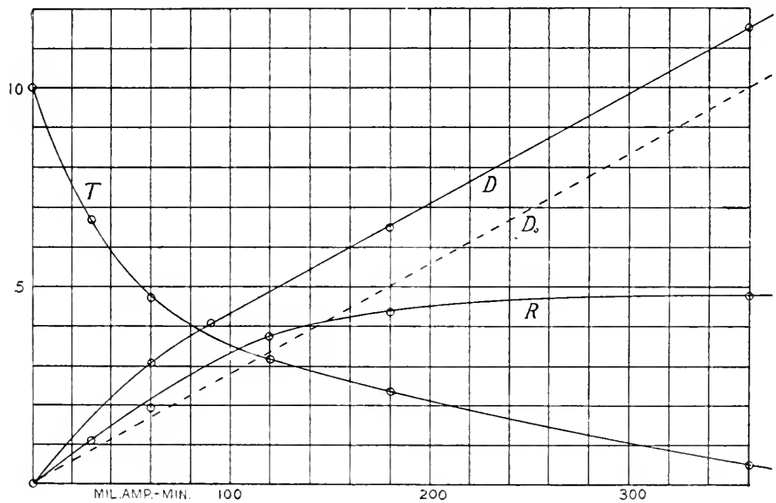
The results show that, as should be expected, the brightness discrimination threshold is a minimum for a minimum of color difference between the two compared stimuli, and that on the average it has a value four or five times its minimum, for a maximum of color difference. The data also indicate that, to the first order of approximation, degree of color similarity is proportional to the extent of participation of the same psychological primary color qualities in both of the compared fields. It is also apparent that the ratio $\Delta I/v$ is independent of the color difference. The general average value of this ratio for subject T is 4.012 (a.d. = .61), and for subject L, 4.09 (a.d. = 1.04). Hence, approximately: $\Delta I = 4\,v$.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

SOME QUANTITATIVE DATA ON CATHODE DEPOSITED METALS.†

By P. G. Nutting.

SOME apparatus developed for the preparation of semi-transparent platinum mirrors, eleven inches square, giving very uniform results, a number of deposits were made to determine the variation of reflecting power, transmission, density, and mass of metal deposited with current density and time of deposit. In the larger apparatus the cathode was $279 \times 279 \times 0.05$ mm., in the smaller $120 \times 120 \times 0.1$, both of platinum with 30 per cent. iridium.



With the smaller apparatus the data shown in the figure were obtained. Abscissæ are milliampère-minutes. The curve R is reflecting power at 45 degrees incidence, T transmission, and D density ($D = \log 1/T$), measured normal to the surface. The dotted line D_o is the density corrected for losses by reflection. Density is proportional to mass of metal, and hence to quantity

* Communicated by the Director.

† Communication No. 33 from the Research Laboratory of the Eastman Kodak Company.

of electricity. Eight points on the curves were obtained at currents of 20, 30, and 60 milliampères and running for from one to twelve minutes.

Mass per unit density and per coulomb were determined on the larger apparatus. Metal was deposited at 60 milliampère current for 12 minutes, or 0.0920 amp.-min./dm.^{2}. The deposited mirror, trimmed to 7.34 dm.^{2}, had a mean density of 0.224 and weighed 0.0125 gm. The mass per square decimetre per unit density is, therefore, 7.6 milligrammes. The silver in a photographic negative has a mass of 9 to 12 mg./dm.^{2} per unit density.

The mass of 1.71 mg./dm.^{2} was deposited by a current of 0.72 amp.-min. over 7.78 dm.^{2}, or 0.0926 amp.-min./dm.^{2}. The deposit was, therefore, 0.0185 gm./amp.-min., or 0.00031 gm./amp.-sec., compared with 0.001118 for silver. Quadrivalent platinum, deposited according to Faraday's Law, would give 0.00050 gm/amp.-sec.

ROCHESTER, N. Y., June, 1916.

Strike-a-lights. H. BRIERLEY. (*English Mechanic and World of Science,* No. 2666, April 26, 1916.)—Only 89 years ago lucifer matches were first sold at Stockton-on-Tees in boxes containing only 50 for a shilling, and some time elapsed before it was possible to buy 25 of them for a sixpence, and at the popular price of "four a penny" they were cheap only to the well-to-do. Elderly people can tell us a good deal about the use of the flint and steel and home-made non-frictional matches. Tinder had to be prepared by burning a few old rags, but some people preferred touchwood to tinder. This consisted of decayed and pulverized wood or bark, or else of certain fungi taken from trees. Tinder-boxes known as "strike-a-lights" or "strike-a-sparks" usually carried their own flint on the lid or base. The world is indebted to one John Walker, a Stockton-on-Tees chemist, who placed on the market the first match lit by friction in 1827.

Brandon, the little Suffolk town, still supplies the world with the primitive flint strike-a-lights, which not even the excellent safety match and wax vesta have not rendered obsolete. British troops during the South African campaign were supplied with Brandon flints —the best in the world—combined with steel, fuse, and lens; while Brandon gun-flints were used at the Battle of Waterloo and during the Crimean War. Spanish and Italian peasants have always been glad to secure Brandon flints, which, in one form or another, constitute part of the outfit of soldiers, travellers, and explorers in tropical lands. The modern flint, steel, and fuse combined is cheap, quite safe, and is contained in the smallest possible space.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, June 7, 1916.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 7, 1916.

MR. C. E. BONINE *in the Chair.*

The following report was presented for final action:

No. 2657.—Paint and Varnish Remover. Edward Longstreth Medal of Merit to Carleton Ellis, of Montclair, N. J., adopted.

The following report was presented for first reading:

No. 2658.—Copes Boiler Feed Regulator.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, June 14, 1916.*)

RESIDENT.

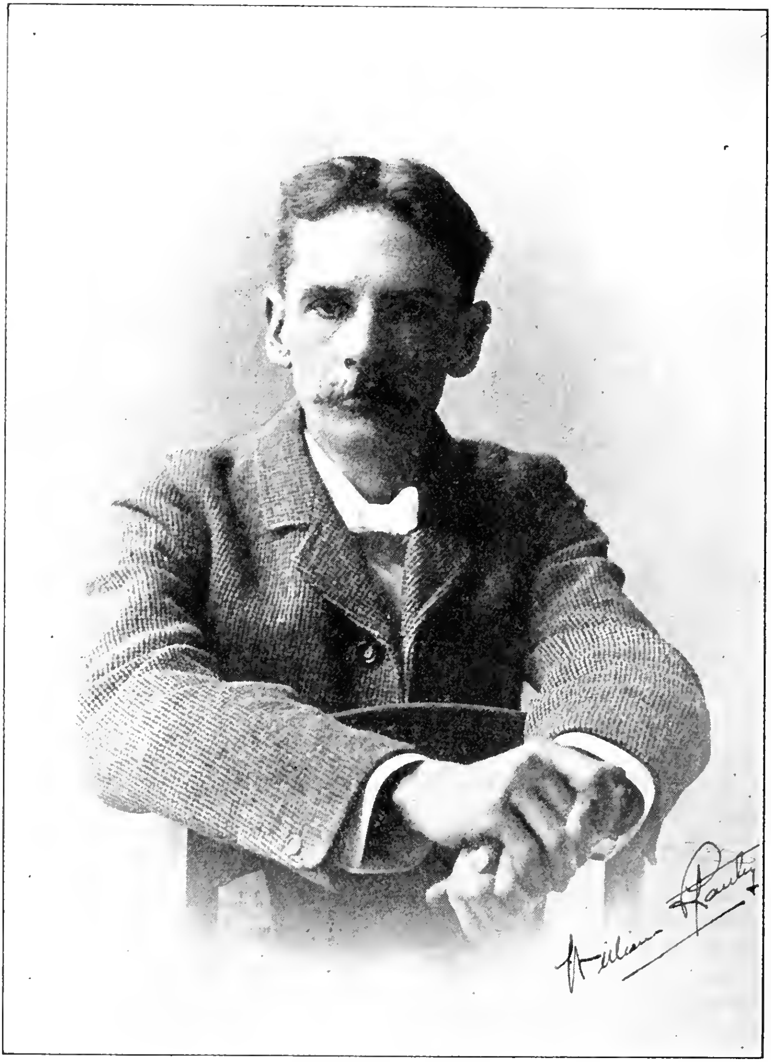
PROF. LESLIE B. SEELY, head of Science Department, Germantown High School, and for mail, 5918 Pulaski Avenue, Germantown, Philadelphia, Pa.

NON-RESIDENT.

MR. G. S. LAWLER, electrical engineer, 31 Milk Street, Boston, Mass.

CHANGES OF ADDRESS.

DR. E. G. ACHESON, Care of The Acheson Corporation, Æolian Building, 35 West Forty-second Street, New York City, N. Y.
MR. ROBERT J. ANDERSON, 10839 Pasadena Avenue, N. E., Cleveland, Ohio.
PROF. W. S. FRANKLIN, Washington, Conn.
MR. TINIUS OLSEN, The Gladstone, Eleventh and Pine Streets, Philadelphia.
MR. GEORGE A. ORROK, R. F. D. No. 2, Willimantic, Conn.
PROF. I. M. RAPP, R. D. No. 3, Phœnixville, Pa.
MR. ROBERT S. REDFIELD, Barnstable, Mass.
MR. C. E. SARGENT, 2020 North Delaware Street, Indianapolis, Ind.
MR. OSCAR L. SCHEHL, St. James Hotel, Woonsocket, R. I.
MR. ALBERT R. SHIPLEY, 186 Canner Street, New Haven, Conn.
LIEUT.-COL. GEORGE O. SQUIER, Signal Corps, U. S. A., care of War Department, Washington, D. C.



WILLIAM STANLEY,
1858–1916.

NECROLOGY.

WILLIAM STANLEY,

1858–1916.

Mr. William Stanley was born in Brooklyn, N. Y., November 22, 1858, the son of William Stanley, a prominent lawyer and a one-time resident of Great Barrington, Mass. The family, two years later, established a permanent residence in Englewood, N. J., where, with the exception of a few years in Berkshire and Williston Academy, Easthampton, William Stanley passed his youth and acquired his early education, largely from private tutors.

After graduation at Williston in 1876, he entered the class of 1881, Yale University.

After leaving Yale, Mr. Stanley was employed by Charles T. Chester & Co., the principal manufacturers of telegraph instruments of that time, but soon left the company to go into the nickel-plating business on his own account.

At that time Mr. Hiram Maxim (now Sir Hiram) came to Mr. Stanley's father for legal assistance in organizing the United States Electric Lighting Company, when young Stanley first became acquainted with him. Subsequently he sold his electroplating business and became one of Mr. Maxim's associates in the manufacture of electrical apparatus. His first invention was an improved system for exhausting incandescent lamps by which a high vacuum could be obtained in a shorter time than was then usual. His pumping system was patented, successfully operated, and is still used by manufacturers of incandescent lamps.

In 1880 Mr. Maxim visited the Paris Exposition, and remained abroad to perfect his rapid-fire gun. Mr. Stanley then joined, for a short time, the staff of Dr. Edward Weston. Later, in 1882, Mr. Stanley started a small laboratory of his own in Englewood, N. J.

At that time the great problem of the economic transmission of electrical energy was pressing for solution, and to it Mr. Stanley devoted his best energies.

In 1884 he became associated with Mr. George Westinghouse, an association which resulted in the Westinghouse Electric Company for the development of his inventions.

In that year Mr. Stanley built several new types of generators and motors, and installed a factory for the making of incandescent lamps, devoting most of his time to development rather than invention.

In the spring of 1885 he made and operated the first "converter," now called "transformer." During the summer and early fall of 1885, although too ill to work steadily, he gave every moment possible to the devising of a system of electrical distribution that should greatly increase the distance over which electric energy could be economically transmitted. It was during this period of illness and before he was able to return to work that Mr.

LOUIS DUNCAN,
1861–1916.

Stanley worked out the elements of the present well-known alternating-current system of transmission and distribution in general use.

In 1886 the first alternating-current plant equipped by the Westinghouse Electric Company was started at Buffalo.

Later Mr. Stanley devised several new kinds of alternating-current generators, two new kinds of alternating-current motors that have been widely used, and, with Mr. J. F. Kelly, he developed a plan for neutralizing the induction on telephone lines. In 1888 he built the first induction wattmeter, an instrument that is used for measuring the energy wherever the alternating-current service is employed.

In 1890 the Stanley Electric Manufacturing Company at Pittsfield, Mass., was organized by Mr. Stanley and his associates, Mr. J. F. Kelly and Mr. C. C. Chesney, which was later absorbed by the General Electric Company.

Mr. Stanley also patented many other devices and methods now widely used in the electrical industries. Lately he devoted much attention to thermal problems.

He was awarded the Edison Medal for his work in developing the transformer and alternating-current systems. Mr. Stanley was a member of many scientific, technical, and engineering societies; he became a member of The Franklin Institute on January 8, 1913.

DR. LOUIS DUNCAN,

1861—1916.

Dr. Louis Duncan was born in Washington, D. C., March 25, 1861, and died February 13, 1916, at Pelham Manor, New York.

He was educated in country schools in Maryland, Virginia, and Tennessee until his entrance into the East Tennessee University. After one year's attendance there he was appointed to the United States Naval Academy from Kentucky, graduating twenty-third in his class in 1880. After two years' cruise in the Pacific Station he took his examination for Ensign, standing first in his class. He was then detailed to Johns Hopkins University to assist in the work of determining the absolute unit of electrical resistance for the United States Government, receiving the degree of Ph.D. for this work in 1885 from the University.

He resigned from the Navy in 1886 to take the Chair of Electricity at Johns Hopkins University, where he continued until 1899. During these years he was continuously occupied in engineering work. He had charge of the construction of a number of electric roads in Baltimore; was consulting engineer for practically all the electric roads in Washington, and was engineer for the Baltimore and Ohio Company and installed the 100-ton electric locomotives which haul trains through the Baltimore Tunnel. He resigned from Johns Hopkins University in 1899 and became chief engineer and had charge of construction of the Third Avenue System in New York. In 1902 he was called to inaugurate the Electrical Engineering Course at the Massachusetts Institute of Technology, remaining as head of the Electrical Engineering Department until his resignation in 1904. As a member of the firm of Duncan & Hutchinson he was consulting engineer for the New York Rapid Transit Commission on

the Subway. He was chief engineer for the Keystone Company of Philadelphia and of the independent telephone systems in Baltimore and Pittsburgh. He was also consulting engineer for the Cincinnati Traction Company, the Indianapolis Traction Company, and a large number of other electric railroad companies in the middle West. He was an expert in many important patent litigations. At the time of his death he was president of Duncan, Young & Company, New York. He was chairman of the Board of Judges at the International Electrical Exhibition in 1884; on the Board of Judges of the Atlanta Exhibition, and of the World's Fair at Chicago, and chairman of the Electric Railroad Section of the St. Louis Exhibition.

Dr. Duncan contributed the articles on "Electric Traction" in the 10th and 11th Editions of the Encyclopædia Britannica and was the author of many scientific papers.

He was lieutenant-commander in the Maryland Naval Reserve, and at the outbreak of the Spanish-American War was appointed major of the First Battalion of the First Regiment of Volunteer Engineers.

Dr. Duncan was a Fellow of the American Institute of Electrical Engineers and twice its president, 1895-'87; a member of the American Electrochemical Society, Société Mathematique de France, Société de Physique, and of many other learned and technical societies in America and Europe. He was elected an honorary member of The Franklin Institute on November 11, 1885, and became an associate editor of the JOURNAL in 1912.

LIBRARY NOTES.

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SENNETT, H., and H. J. ORAM.—The Marine Steam Engine. 1915.
TRUDELLE, V.—La Lumière électrique an théatre. 1914.
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The Strength of Clamped Splices in Concrete Reinforcement Bars. E. L. LASIER. (*Proceedings of the American Society for Testing Materials*, June 27 to 30, 1916.)—Concrete reinforcement bars are received in lengths varying up to about 60 feet. The length most commonly selected, however, is in the neighborhood of 30 feet; hence it is frequently necessary in practice to lap one bar over another. It is also desirable upon more or less frequent occasions to secure a splice capable of withstanding a greater tensile stress than that which a plain lap splice can resist. In such cases, U-bolt clamps, such as are ordinarily used in fastening wire cables together, have been successfully employed, one at each end of the overlapping bars. The meagreness of available data on the strength of such splices prompted the tests, the results of which are here recorded.

U-bolt clamped splices of both 17- and 21-inch lengths of splice were tested to determine the load at first slip, and the maximum load the splice would resist. Three different classes of splices were thus tested: Lap splices not embedded in concrete; butt splices not embedded in concrete; lap splices embedded in concrete. The reinforcement steel in all cases consisted of 1-inch square cold-twisted bars.

The loads necessary to produce first slip had a range from 7000 to 50,000 pounds. The maximum load which the splices withstood varied from 23,000 to 69,000 pounds. The ratios of load at first slip to yield point of bar for clamped splices not embedded in concrete varied from 12 to 21 per cent., and for splices embedded in concrete from 53 to 83 per cent. Ratios of maximum load to tensile strength of bar ranged from 31 to 61 per cent. for unembedded splices, and from 79 to 95 per cent. for embedded splices.

It was found: (1) That lap splices are stronger than butt splices. (2) That splices in which the two overlapping bars are of opposite twist apparently are stronger than splices in which the bars are of like twist. (3) That the lengths of lap, as to the two lengths tested, did not affect the strength of the splice. (4) That embedding the splices in concrete increases their strength materially. (5) That clamped lap splices embedded in large masses of concrete undoubtedly can safely withstand a unit load equal to the unit stress of the steel reinforcement.

CURRENT TOPICS.

Refinements in Illumination. ANON. (*Electrical Review,* vol. 68, No. 23, June 3, 1916.)—Nothing better illustrates the flexibility of electric lighting than special applications in which the central-station engineer or the fixture designer solves a problem on a plane above ordinary practice. It is no exaggeration to say that the industry has only begun to appreciate its opportunities in this field. Some of these problems may be stated to advantage. There is a demand now, limited, to be sure, but considerable when the possibilities are studied, in the way of providing efficient illumination for the pulpit in chapels serving the deaf, so that lip-reading can be done by the congregation, which cannot get the preacher's meaning by the ordinary methods of communication. Temporary installations have been made which are much better than many of those where no special study has been given to the problem, but in the provision of suitable apparatus to gain the above result without disturbing glare the illuminating engineer can find an interesting and promising test. The need of an installation of this kind was expressed in a recent article in a church periodical by a clergyman experienced in ministering to the deaf, and without question the refinements of modern illumination are equal to the problem.

There is a possibility that the not distant future may witness a demand for a new type of art-museum illumination; that is, for an installation in which artificial light will completely supersede daylight. It is a question whether efforts to maintain a double standard of lighting in such places are worth while, in view of the difficulties of securing equally good results with both. It is also worth investigating whether the use of electric lighting with suitable reflection and diffusion may not be better adapted to the maintenance of life in delicate exhibits, like certain entomological specimens, animal skins, and even tapestries to which a prolonged daylight exposure may be detrimental. Certainly the day has come when the use of museums at night is a consideration of some importance in the large centres, and there is no doubt that conference between the illuminating engineer and the curator might work out plans of lasting benefit to both. A museum load on the daylight schedule makes pretty satisfactory long-hour business from the central-station standpoint.

Other opportunities lie ahead of the lighting expert in the fields of hospital ward and private-room illumination, in the more artistic and better-diffused lighting of hallways in old apartment houses, in the concentration of luminous flux on street-corner signs, and in the adoption of the principles of short-range flood lighting to the requirements of fine residences. The variety of such problems in matters of detail is amazing, and every time one of these is well solved the whole art of illumination is advanced, with a correspondingly im-

proved outlook for the commercial side of such work, even down to the greater sale of supplies and the increase of central-station outputs.

Coal Mine Illumination. R. E. SIMPSON. (*Transactions of the Illuminating Engineering Society*, vol. xi, No. 2, March 20, 1916.)—Coal mining ranks as one of the most dangerous industries in which man is engaged, and this is true not only because of the high accident rate, but also because of the serious nature of many of the accidents. One of the factors that contribute to this high accident rate is the inadequacy of the illumination in coal mines. There are very few industries, if any, in which the illumination is so wretched and at the same time where good illumination is so necessary for the safety of the men. But the problem of providing adequate illumination in a coal mine is not easily solved. The use of illuminating gas is out of the question: first, because the open flame will ignite methane and cause explosions; second, because illuminating gas is itself so explosive that no mine owner would permit the introduction of such a hazardous element in the mine; and, lastly, because the cost of piping would be prohibitive. The use of electricity is likewise impracticable, because the cost of wiring the miles and miles of entries and working places precludes it, except at important switching points. There remains, then, only some form of portable light available for general coal mine lighting.

In the early days of coal mining, and even to-day in some instances, candles were used at the working places and along the haulage roads. Under average working conditions, they rarely gave a full candle-power; a fair average would be 0.8 candle-power. In addition to their inadequate power, like all open-flame light sources, they are unsafe in gaseous mines. The open-flame oil lamp, giving from 1 to 4 candle-power, consisting of a metal oil container and a spout for a cotton wick, was next introduced. With crude petroleum, which is generally used, they give a deep orange color, smoky flame, and their flickering light is very trying on the eyes. These open-flame lights exposed the mines to the danger of explosion of methane, however, and this condition made necessary the use of a light that would not ignite the gas. The safety lamp, which is essentially a cylinder of gauze placed about the flame, not only prevents the flame from igniting any gas that may be present, but is also used to indicate the percentage of gas present by the variation in size of the cap at the tip of the flame. Considered for illuminating qualities only, these lamps leave much to be desired. They seldom give more than 1 candle-power, and, under working conditions, from 0.2 to 0.5 candle-power with poor distribution. The acetylene lamp, known among miners as the "carbide lamp," is by far the best open-flame lamp in use in coal mines to-day. With a reflection equipment it gives a light of 4 to 6 candle-power, smoke-free, and whiter than that of the other lamps mentioned.

The storage-battery electric lamp, commonly known as the electric cap lamp, has many advantages over the other types. It emits neither smoke nor odor, and when equipped with a proper reflector a lamp of 1 candle-power will project a beam of light five to ten times as great through an angle of 130 degrees. As its advantages become better known, it may be expected to replace the other types now in use.

The Marseilles-Rhone Canal. ANON. (*The Times* (London) *Engineering Supplement,* No. 499, May 26, 1916.)—The piercing of the Rove tunnel on the Marseilles-Rhone Canal was formally celebrated at the beginning of this month, and the event marks an important stage in an enterprise which has been under construction for a considerable time and has been contemplated for still longer.

The idea of a canal which should enable barges to reach the Rhone from Marseilles without traversing the Mediterranean and the mouth of the river is nearly a century old, but, though various plans have been put forward from time to time, it was not till 1903 that the project was sanctioned as a part of the large scheme for the development of inland navigation in France. From Marseilles the canal runs along the coast as far as La Lave, separated from the sea by a dike, and then, turning northward, passes under the hills in a tunnel which has now been pierced. On emerging from the tunnel it passes through a cutting over a mile in length and nearly 100 feet deep at the deepest point, and then, skirting the southern side of the Etang de Berre, passes through Martigues to Port de Bouc, on the Gulf of Fos, whence it utilizes an existing canal to Arles on the Rhone. Its total length is about 48 miles, and the cost is estimated as over three and one-half millions sterling.

The tunnel, which accounts for more than two-thirds of this sum, was begun in 1910. It is about four and one-half miles long and 72 feet wide, and has a towing path six and one-half feet wide at each side, leaving 59 feet for the waterway proper. The depth of the water through the tunnel between Marseilles and Etang de Berre is nearly 10 feet, and 8 feet in other sections. The locks are to have an available length of nearly 525 feet and an entrance width of 52½ feet, or double the beam of the 600-ton Rhone barges. Although the work is hampered by the war, it is hoped to have the canal ready for traffic in three years.

Ernolith: A New Celluloid Substitute. ANON. (*Scientific American*, vol. cxiv, No. 24, June 10, 1916.)—It is only in recent years, and largely owing to the researches of the Berlin Institute of Fermentive Industries, that the very remarkable properties of yeast, aside from its levitating power, have been realized. Not only can valuable extracts be obtained from it, useful as flavoring matter and for tonic and medicinal qualities, but it contains a relatively large percentage of protein, or albuminious matter. Finally, the mass of

cellulose, its remaining constituent, composed of uncommonly tiny and delicate cells, is capable of various reactions with other substances. This latter property has been taken advantage of for the formation of plastic masses by combination with aldehydes. When these masses are subjected to heat under pressure a hard solid is obtained, known as ernolith, which makes an excellent substitute for celluloid, ebonite, galalith, bakelite, reşinite, etc.

Two research chemists, H. B. Blücher and E. Krause, whose work is reported in the *Chemiker Zeitung*, have been able to vary the degree of hardness and elasticity of this product within certain limits. The color, which is originally black, can also be varied by the incorporation of mineral or vegetable dyes, so that shades of yellow, gray, brown, red, green, and blue can be obtained, as well as marbled or veined effects. To the fundamental components of ernolith, yeast, and aldehyde (particularly formaldehyde), other constituents may be added which cause a modification of the chemical and mechanical properties.

The process of manufacture consists of two phases: first, the union of the yeast and the aldehyde (with various "fillers" and subsidiary reactions). The mass thus obtained is dried and ground, and in this form is indefinitely durable. This powder is known as "half fabricate" or "raw ernolith." The next step is its compression in heated hydraulic presses. The articles thus obtained are said to reproduce on their surface the most delicate details of form, such as, for instance, those of relief maps, etc. Aside from this capacity for being directly moulded, ernolith is capable of being sawed, filed, bored, turned, engraved, ground, polished, and otherwise mechanically acted upon. It has an exceedingly close, dense structure and a conchoidal fracture. As remarked, the process may be so varied as to make the product very hard and brittle, or softer and more elastic, as may be required. It possesses a very decided advantage over celluloid in being almost entirely uninflammable, being very difficult to char. Another valuable property lies in the economy of production, since the raw powder may be precisely measured, thus avoiding trimming and scrap. Its specific gravity when pure (*i.e.*, without fillers) is 1.33 to 1.35. Ernolith also has the quality of adhering very tightly to metal threads and tissues pressed into it. This makes it highly adapted to the manufacture of articles with a metal surface or core. As primary material, it is possible to employ not only the ordinary waste yeast of breweries, but also the "air-made" yeast of the Delbrück process.

Five Years' Progress in the Industrial Fellowship System. (*University of Pittsburgh*, March 1, 1916.)—In March, 1911, the late Robert Kennedy Duncan inaugurated the Industrial Fellowship System at the University of Pittsburgh, in the Department of Industrial Research, now known as the Mellon Institute of Industrial Research of the University of Pittsburgh. The Industrial Fellowship

System represents a sane, practical plan of coöperation between industry and learning for increasing the efficiency of American industry.

The first Fellowship was founded through a grant from a baking company, which desired to improve its product. The sum of money given by this concern was used, as has been all the money which has been contributed to Fellowships, with the exception of small sums for the purchase of apparatus and chemicals, to secure the services of a man who had shown a gift for research, to devote all his time to certain problems connected with the baking industry.

During the five years which have elapsed since the establishment of the first Fellowship, 47 distinct concerns have endowed some 105 one-year Fellowships. They did this in the belief that the Mellon Institute was in position to mobilize and to concentrate all of the advantages and opportunities known to science for the solution of their particular problems. The new building of the Institute is the most complete and modern industrial experiment station in the country, and, together with the permanent organization and connection of the Institute, gives very exceptional advantages for the successful prosecution of industrial research work.

The total amount of money contributed to the Institute for the five years ending March 1, 1916, was $360,400. In addition to this sum, over $300,000 was expended by these concerns in the construction of experimental plants and $21,300 was awarded in bonuses to Fellows for the successful completion of problems.

During the five years the Institute itself expended about $175,000 in taking care of the overhead expenses in connection with the Fellowships. Besides this amount, the new building and the permanent equipment of the Institute represent an investment of between $300,000 and $350,000.

That the results obtained under the Industrial Fellowship System of the Mellon Institute have justified the expenditure of these sums of money, both on the part of industrial concerns and the Institute itself, has been shown by the fact that during the first four years—March, 1911, to March, 1915—seven out of each ten problems assigned to the Institute for study were solved to the satisfaction of the donors. A large percentage of the Fellowships were renewed, showing the confidence which industrialists have in the Institute. Twenty-five patents have been granted to the holders of Fellowships, and there are as many more pending. Above all, some twenty new processes developed in the Institute are now in actual operation on commercial scales.

At the close of the first five years of the Industrial Fellowship System at the Mellon Institute, it can be said that the plan of coöperation between science and industry which it represents has demonstrated its genuine value to American industry, and that the Institute looks forward with hope and confidence to its future development.

The Ignition of Gases by Impulsive Electrical Discharge. W. M. THORNTON. (*Proceedings of the Royal Society*, Series A, vol. 92, No. A641, May 6, 1916.)—The ignition of gases by impulsive discharge is considered first as a function of sparking distance. It is shown that the shorter the distance the greater the spark, so that the volumes of the least igniting spark are, in a typical case, the same for all spark lengths. Ignition may occur with intense momentary brush discharge, generally with the true disruptive sparks. The products of combustion are found to be ionized and to carry a positive charge.

The gases examined were mixtures in air of hydrogen, methane, propane, and pentane; ethylene and acetylene; carbon monoxide and cyanogen; coal gas and a mixture of equal volumes of hydrogen and methane. Hydrogen, propane, pentane, and carbon monoxide rise gradually in difficulty as the percentage of oxygen is reduced; methane is ignited by the same spark, whatever the percentage of gas may be; acetylene and cyanogen have the stepped atomic type of ignition; ethylene is more inflammable in rich mixtures. Hydrogen and methane in equal volumes are ignited as methane in type, hydrogen in magnitude.

The limits of inflammability of the paraffins are shown to be reached: the upper limit when there is twice the volume of combustible gas to that in the mixture for perfect combustion, the lower limit when the volume of oxygen is twice that for perfect combustion, less 1 atom to the molecule. The ignition of coal gas is through methane. Four types of electric ignition are given, covering all from the most rapid to the slowest rate of discharge from the poles. The work gives direct evidence that ignition begins by ionization of the oxygen in the mixture.

The Absorption of Gas by Quartz Vacuum Tubes. R. S. WILLOWS and H. T. GEORGE. (*Proceedings of the Physical Society of London,* vol. xxviii, part iii, April 15, 1916.)—It is a common experience to those who work with vacuum tubes, once the electrodes are freed from gas, the continued passage of the discharge lowers the pressure, and the tube eventually evacuates itself to such an extent that further discharge is impossible. This gives rise to much trouble in X-ray technic, and, as gas pressure regulators have to be added, complicates the construction of the tubes. These disadvantages have only recently been surmounted in the well-known but costly Coolidge tube. It is, therefore, a matter of great practical importance to gain some knowledge of this process of self-evacuation.

The experiments are a continuation of those of Willows and Hill on the absorption of gas which is brought about by the electrical discharges. A new quartz bulb does not absorb air, but if it be fed with repeated doses of hydrogen—which are absorbed when an electrodeless discharge is passed—it then becomes very active. If dis-

charges in hydrogen are alternated with those in air the bulb can be made to absorb large quantities of either gas, and the activity with each gradually increases. The authors reject the theory of surface absorption and, in their own experiments at least, also Swinton's theory that the gas is shot into the walls and held there. It is supposed that chemical actions occur with air, and oxidation products are formed; these are reduced by hydrogen. The process is compared with the formation of the plates in a Planté cell. Attempts to produce the same effects by chemical treatment are partially successful, particularly in fatiguing the bulb so that no further absorption takes place. The conditions under which the primary and secondary hydrogen spectra appear are also described.

Effects of Atmospheres Deficient in Oxygen on Small Animals and on Men. G. A. BURELL and G. G. OBERFELL. (*Bureau of Mines*, Technical Paper 122, November, 1915.)—In studies of the composition of mine atmospheres as related to the health and safety of miners, the writers of this paper have observed that small animals, such as mice and canaries, are not quickly sensitive to atmospheres deficient in oxygen, and hence may not indicate to exploring parties in mines that the oxygen content of an atmosphere is dangerously low. For this reason a series of tests was conducted to determine the sensitiveness of canaries and mice to such atmospheres; also, some information was obtained as to the effects of such atmospheres on men.

Deprivation of oxygen was found to cause collapse in men about the same time as it does in mice and canaries. The animals may collapse in atmospheres of different composition, and presumably the same is true of men. The fact is evident that birds and mice cannot be used safely as indicators of atmospheres low in oxygen by exploring parties in mines. Canaries are slightly more susceptible to "oxygen want" than are mice, and are chiefly valuable for indicating the presence of carbon monoxide, to which they are much more susceptible than man. In mixtures of air and nitrogen containing about 7.6 to 7.8 per cent. oxygen, canaries show pronounced distress. When the oxygen content is about 7 per cent. mice show considerable distress, and a man is in grave danger of dying; hence canaries and mice should not be used by exploring parties in mines to show when men unequipped with breathing helmets should retreat, because the atmosphere is low in oxygen. Mice and canaries, especially the latter, are chiefly of value for indicating to exploring parties the presence of dangerous proportions of carbon monoxide. In an atmosphere in which oil-fed lamps will not burn, an exploring party should not depend upon canaries for further guidance, but should use breathing apparatus in advancing into the atmosphere.

The Extraction of Gasoline from Natural Gas by Absorption Methods. G. A. BURELL, P. M. BIDDISON, and G. G. OBERFELL. (*Metallurgical and Chemical Engineering*, vol. xiv, No. 11, June 1, 1916.)—The absorption method of extracting gasoline from natural gas consists in bringing natural gas in contact with an oil heavier than gasoline, *i.e.*, a petroleum distillate of about 34 deg. Baumé, letting the absorbent absorb the gasoline from the natural gas, and then separating the gasoline from the oil by distillation. The oil is simply used as a carrier of the gasoline from the absorption tank to the still. It is used over and over again.

This method is different from the extraction of gasoline from casing-head natural gases by the compression and condensation method. By the latter method, natural gases that are comparatively rich in gasoline vapor are treated, *i.e.*, those carrying upwards of 3/4 gallon of gasoline per 1000 cubic feet of natural gas. So-called "dry" natural gas cannot be treated by this method. By "dry" natural gases are meant those used in cities, towns, and factories for heating, lighting, and other purposes. The quantity consumed of this kind of natural gas amounted, in 1914, to 591,000,000,000 cubic feet. Most of this natural gas carries gasoline to the extent of one to two pints per 1000 cubic feet of gas. Probably 75,000,000 gallons of gasoline per year can be obtained by treating much of this natural gas at the present time. In the case of two natural gases that the authors of this paper experimented with, the heating value was lowered only 3.8 per cent. in one case and 2.2 per cent. in another case by the extraction of the gasoline. Besides the obtaining of valuable fuel, gasoline, a further advantage of the process lies in the resultant protection of pipe lines against the deteriorating effect of gasoline on coupling rubbers.

The absorption process of extracting gasoline from natural gas assumed industrial importance as the demand for gasoline increased. The scheme is practically identical with the process of extracting benzole and toluol (light oil) from coke-oven gases, a process used for years in Germany and to a very large extent during the years 1915 and 1916 in the United States. A difference lies in the fact that coke-oven gases are treated at about atmospheric pressure, while natural gas is treated at pressures as high as 200 to 300 pounds per square inch. This is an economic necessity, because natural gas is transported at high pressures and it is not desirable to disturb the system. To the best of the authors' knowledge, the first large-scale installation for extracting gasoline from natural gas by the absorption process was placed in Hastings, W. Va., by the Hope Natural Gas Company, of Pittsburgh, Pa.

All natural gases, except those that contain methane only as the combustible gas, contain gasoline vapor. However, in some cases, the amount contained may be very small. This is sometimes due to the fact that gas wells are under very high pressures, and this high pressure keeps the gasoline back in the well. But even those high-

pressure wells represent potential sources of gasoline supply, in that natural gas will carry commercial quantities of gasoline vapor as the pressure declines. Natural gas from two different fields that the authors tested contained gasoline to the extent of one pint per 1000 cubic feet in one case and 1.5 pints in another case. About 50,000,000 cubic feet of natural gas per day were available for treatment.

Oils which the authors experimented with to act as absorbents for the gasoline were about 35° Baumé specific gravity and started to boil at about 400° to 462° They were petroleum distillates. It is necessary that their boiling-point be much higher than the boiling-point of gasoline to make the extraction of the latter by distillation easy. Some tests were made in which the natural gas was simply passed into a naphtha of about 55° Baumé. Yields varying between 300 and 500 per cent. greater than that by the oil absorption and distillation process were so obtained.

Permanence of Writing-Ink. D. B. DOTT. (*Journal of the Society of Chemical Industry,* vol. xxxv, No. 9, May 15, 1916.)—Attention was first called to the bleaching effect of air and light on writing-ink, as used in modern times, by the fact that signatures on certain certificates had become illegible through the fading of the ink. As it was impracticable to test a sample of ink by exposure of writing for a period of years, it was considered that a limited application of hydrogen peroxide would be the nearest chemical equivalent to the bleaching effect of the atmosphere. Writing done by different inks was exposed to light, the paper being occasionally moistened with a 3 per cent. solution of hydrogen peroxide, the result being that the handwriting gradually became invisible, in some cases more quickly than in others. Taking ferric tannate, indigo, and aniline-blue as the principal substances used in making writing-ink, it was found that all of them are rapidly decolorized by warming with hydrogen peroxide solution. With solutions of these substances in test-tubes at the ordinary temperature the same change was slowly produced. The violet ink used for typewriters was less readily acted on, but was quickly bleached by sulphurous acid. If an ink could be produced possessing the desirable properties of perfect fluidity and being non-depositing, and at the same time incapable of being decolorized by oxidizing or reducing agents, there would be good reason to believe that the writing done by such an ink would be practically permanent. In the meantime, when writing is of an important nature and is desired to endure, some form of carbon ink appears to be the only trustworthy preparation.

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EXPERIMENTAL RESEARCHES ON THE SKIN EFFECT IN STEEL RAILS.*

BY

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THE following research was conducted during the years 1914–15–16, at the Massachusetts Institute of Technology, under an appropriation from the American Telephone and Telegraph Company. In the earlier part of 1914, it was conducted under the directorship of Prof. Harold Pender. The research originated in a thesis at the Massachusetts Institute of Technology in 1913–14, by Mr. R. W. Weeks, in the Department of Electrical Engineering.

Objects of the Research.—The research was made to determine, by direct measurement, the impedance offered, to alternating currents of the strengths likely to be employed in electric-railway work, by standard steel rails of various shapes and sizes; also, to ascertain how this impedance varied with frequency and with current-strength, and whether the impedance could be reduced to a simple engineering theory, so as to admit of being predicted, within reasonable limits, from physical data concerning the steel used in the rails. It is believed that some progress is here presented in each of these directions.

Types and Dimensions of Rails Tested.—The tests were extended to 11 sample track rails and 2 sample contact rails, 33 feet

* Communicated by Dr. Kennelly, April 14, 1916.

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(10.07 metres) in length, ranging in linear mass from 60 to 100 pounds avoirdupois per yard (30 to 50 kilogrammes per metre), with corresponding cross-sections from 6 to 10 square inches (38.5 to 64.5 square centimetres). The cross-sections of these rails are represented to scale in Figs. 5 to 10.

Frequencies and Strengths of Alternating Testing Current.—Three frequencies have been used in the tests; namely, 25, 45, and 60 cycles per second. The bulk of the work was, however, carried on at or near two frequencies only; *i.e.*, 25 and 60 cycles per second.

The current-strengths employed in the test rails varied from 10 to 800 ampères r. m. s.

FIG. 1.

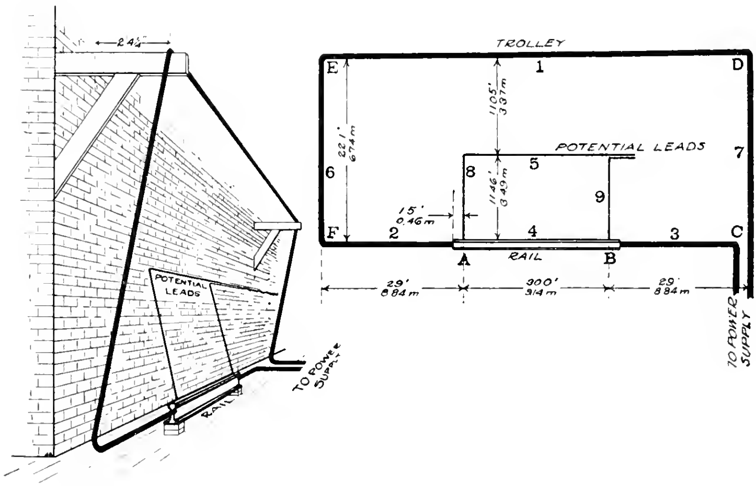
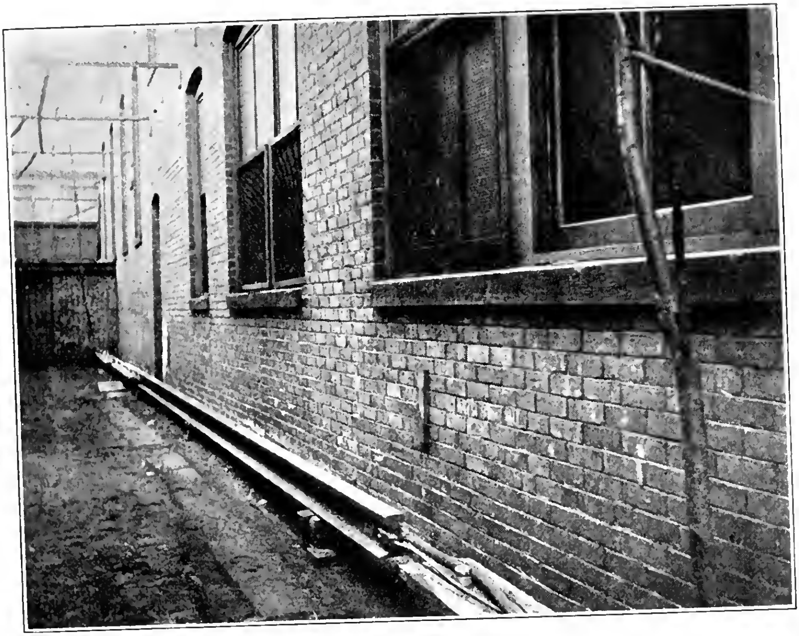


Diagram of test circuit.

Arrangement of Test Circuit.—In order to make the measurements as nearly under practical railway conditions as possible, the test circuit was so constructed that the rail and its parallel return conductor occupied the same relative positions as one rail of a railroad track and its overhead trolley wire (No. 0000 A. W. G., diameter 0.46 inch, or 1.17 centimetre); *i.e.*, with the trolley wire 2 feet 4½ inches (71.8 centimetres) to one side of the rail and 22½ feet (6.86 metres) above it. The arrangement of the test circuit is shown in Fig. 1. *AB* is the rail under test, occupying a horizontal position raised about 1 foot (30 centimetres) above

the ground on brick pillars. The rest of the rectangular loop *BCDEFA* was composed of straight copper conductors (wire or cable). The extensions *AF* and *BC* from the ends of the rail were made so as to enable the electro-magnetic field in the neighborhood to be both more nearly uniform and more readily calculated. The circuit was erected in an alley between two brick buildings, remote from iron. A photograph of the rail in position appears in Fig. 2.

FIG. 2.

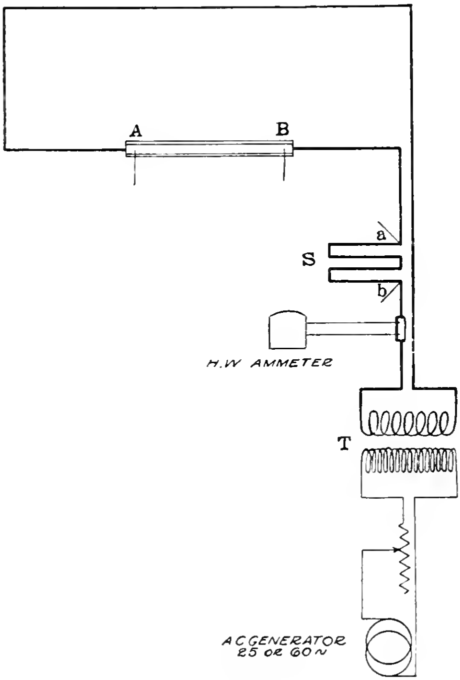


Rail in position for test.

Sources of Alternating-current Supply.—For the frequency of 25 ∾, a General Electric 3-phase 50-kva. alternator, 6-pole 514 r. p. m.—230 volts—126 ampères was used. For the frequency of 60 ∾, a Mordey single-phase, 40-kva. alternator was used, with 9 poles and 9 pancake coils, for supplying about 135 ampères r. m. s., at about 300 volts. The arrangement of circuits used is shown in Fig. 3. The transformer *T* was a General Electric Company's 15-kva., 60 ∾, single-phase transformer from 220 to 18 volts. The secondary terminals were connected directly to the test circuit through two four-terminal manganin resistors, and the

primary terminals to the generator through an adjustable rheostat having very little inductance. At the frequency of 25 ∾, and maximum rail current, the primary voltage impressed on the transformer was about 230 volts, with 130 ampères or 29.9 kva. with 12.5 kw. At the frequency of 60 ∾, the corresponding primary voltage on the transformer was about 330 volts, with 125 ampères. Occasionally, tests were also made at 60 ∾, with currents from

FIG. 3.



General testing connections from generator.

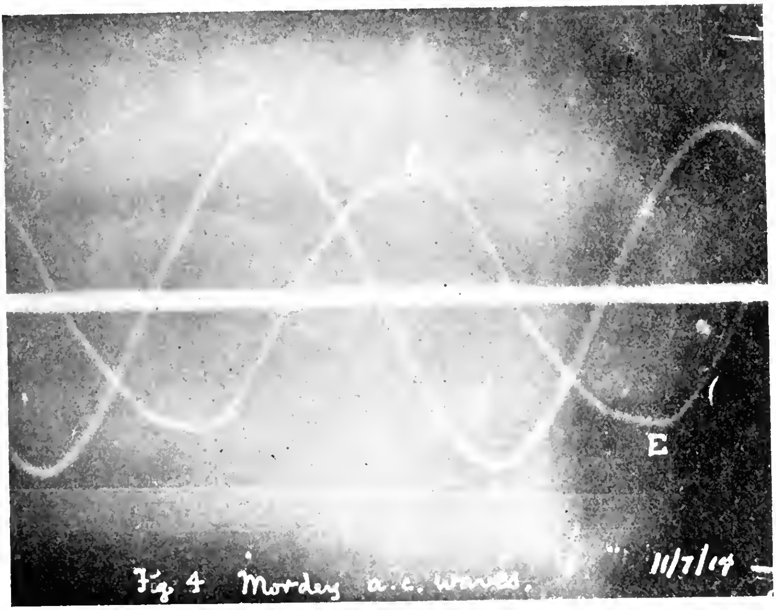
the shop mains, supplied by a General Electric Company's 14-pole, 100-kva., three-phase alternator.

The wave-form of voltage and current supplied from the Mordey generator was nearly sinusoidal, as was shown by numerous oscillograms (see Fig. 4). The wave-form of 25 ∾ voltage, from the 50-kva. generator, showed appreciable harmonics; while the wave-form of its current showed only a moderate triple-frequency harmonic. The wave-form of 60 ∾ voltage and current from the shop mains had yet more marked harmonics.

Method of Measurement.—Since no exact theory of skin effect in steel rails has yet been worked out, it was very desirable to apply more than one method of measurement, in order to secure a satisfactory experimental check upon the results. Much time had to be expended in finding two different methods of testing which would give concordant results, with steel rails, to the requisite degree of precision.

The following were the four methods tried:

FIG. 4.



Mordey a.c. waves.

Method 1.—By *astatic electrodynamometer* of fixed and moving coils, measurements were made of rail r. m. s. voltage and of rail r. m. s. current, as well as the active power expended in the rail. By an astatic dynamometer is meant one whose moving system comprises two oppositely wound coils, so arranged as to be substantially unaffected by local stray magnetic fields, either alternating or continuous. Denoting the fixed coils by F and the moving coils by M, the voltage across the rail potential points was measured with F and M in parallel, M having a suitable non-inductive resistance in its branch. The circuit current was meas-

ured by observing the voltage across the manganin strip potential points in a similar manner. The active power in the rail was measured by connecting F to the manganin strip, and M to the rail potential points, through a suitable non-inductive resistance. The dynamometer was calibrated by known continuous current passing through both coils. This method was found to be unsatisfactory. Not only does the impedance of both F and M vary to the harmonics in the traversing currents, but the mutual inductance between F and M also comes into consideration, and this varies with the deflection and angular position of M with respect to F.

Method 2.—Oscillographic measurements were made of both the voltage between rail potential points—hereafter called the "rail voltage"—and the current in the rail circuit. Fig. 4 shows one of the oscillograms obtained with 160 ampères in the rail circuit at 60 ∾ and about 0.72 volt across the rail, the current lagging about 71 degrees behind the voltage. The current wave is seen to be nearly sinusoidal; while the voltage wave shows faintly the presence of harmonics. From these two curves it is theoretically possible to compute the impedance of the rail, and, therefore, its skin effect, when its resistance to continuous currents is known. This method, although useful and convenient as a check, was found to be unsatisfactory in detail, owing to lack of precision in the oscillograms, and also to variations in the constants of the oscillographic vibrators.

Method 3.—The Drysdale-Tinsley alternating-current potentiometer * was used at the frequency of 60 ∾, measuring alternately the vector voltage across the rail and the manganin shunt. The ratio of these two measurements gives the vector impedance of the rail between potential points. This method has the advantage that, since the vibration-galvanometer of the detector circuit is tuned to the fundamental frequency, the harmonics in either voltage or current are virtually excluded, and also that the two measured values, $E \angle \alpha$ volts and $I \angle \beta$ ampères, give as their quotient $Z \angle \gamma = \frac{E}{I} \angle \alpha - \beta$ ohms. This reduces the computation of the results to a minimum. Referring to Fig. 3, the alternating-current vector potential difference was measured between points A and B on the rail, and then between points ab on the manganin strip.

A disadvantage of the alternating-current potentiometer

* Bibliography No. 17.

method is its sensitiveness to slight changes of frequency, in the vibration galvanometer and in the phase-splitting device. Under shop conditions of generator driving, it is often hard to keep the frequency constant within satisfactory limits.

Method 4.—The Sumpner dynamometer * was used to measure the current I ampères in the rail, and also to measure both active and reactive components of the rail voltage, which may be called E_R and E_x volts respectively. Then the effective resistance of the rail is $R' = E_R/I$ ohms, while the effective inductance is $L' = E_x/(\omega I)$ henrys. An outline of the theory of the use of this instrument is given in Appendix I.

In all four of the above methods, the p. d. on the tested rail was taken from two potential taps near the ends, and 30 feet (914 cm.) apart. Only two methods, viz., numbers 3 and 4, were found to give uniformly consistent results to the desired degree of precision. Tests made of the impedance of a rail by these two methods—*i.e.*, by Drysdale potentiometer and by Sumpner dynamometer—were found not to differ by more than 3 per cent. within the entire range, including discrepancies attributable to temperature variations, and they usually agreed within 1 per cent. Check tests were also made by both methods on the impedance of copper-rod and copper-strand conductors in place of the steel rail, with satisfactory agreement between them. Having thus obtained, after many trials, two fairly consistent methods of measurement, the Sumpner dynamometer method was finally selected as the best adapted to the local testing conditions, reserving the alternating-current potentiometer for occasional checks. Although this dynamometer method is theoretically subject to errors of extra skin effect, due to harmonics in the rail current and voltage waves, this error was not found to be serious. In the first place, the waves of rail current and voltage have not been very distorted, and, in the second place, the average dynamometer action is zero between a current of fundamental frequency in one coil and a current of any harmonic frequency in the other. Moreover, the harmonic component actions, being subject to differential distortion in phase by the reactances in two-coil circuits, are likely to be diminished in effect.

* The Sumpner dynamometer method has the disadvantages (1) that it is not a null method and (2) that it is not free from the effects of harmonics (*Phil. Mag.*, vol. 20, 1910, p. 309).

The Manganin Strip.—In order to supply a working p. d. in phase with the rail current, a manganin resistance strip was employed in the rail circuit, marked *S* in Fig. 3, and provided with two pairs of potential terminals, one across 2788 microhms, and the other across 933 of these microhms. This strip is made of two separate parallel plates of manganin 58.3 cm. (23 inches) long, 10.2 cm. (4 inches) broad, and 1.3 mm. (0.05 inch) thick, separated by mica insulation 1 mm. (0.04 inch) thick; so that the resistor is in the form of a very flat loop with the going and return conductors separated only by a sheet of mica. This strip was supported horizontally in a bath of oil, to keep it cool, when carrying currents above 400 ampères.

Direct-current Resistance Measurements.—In order to determine the skin-effect resistance ratio, it was necessary to measure the direct-current resistance of each rail at various times during a series of observations, and also the temperature coefficient of the rail's resistivity. This was done by direct-current potentiometer measurements in the usual way.

Temperature Measurements of the Rails.—The temperature of the rail was observed by thermometer, both before and after the measurement of impedance, at each current-strength in a test series. The thermometer was laid upon the rail, and had its bulb protected with a pad of putty. The rail currents above 100 ampères appreciably affected the temperature of the rail. Rail currents of about 750 ampères, during the time of application necessary for the measurements, sometimes raised the rail temperatures to 20° C. above that of the surrounding air. In order to avoid unduly large changes of temperature during a test, the highest current-strength was first applied, for a sufficient length of time to reach substantially constant temperature before the first measurement was made, after which the rail was allowed to cool off slowly as the testing current strengths were successively reduced.

Method of Connecting the Main Leads to the Ends of the Rail.—The rail ends had a hole of about 2 cm. ($\frac{13}{16}$ inch) diameter about 7.5 cm. (3 inches) from the ends. The web of the rail was scraped and cleaned near these holes, and copper lugs clamped firmly against the web by steel bolts passing through the holes. The contact resistance at these junctions was sufficiently low to prevent the junctions from getting unduly hot.

Situation of Potential Leads with Respect to Rail Circuit.—In measuring, by potentiometer, the direct-current potential difference between a pair of terminals on a rail, the disposition of the potential leads with respect to the rail circuit is of no material consequence, assuming that proper insulation is maintained. In measuring alternating-current potential differences, however, the disposition of the potential leads with respect to the rail circuit becomes of great importance, since the mutual inductance between these circuits will cause an induced electromotive force to be developed in the potential circuit over and above that due to the vector IZ drop sought, where I is the current and Z the rail impedance. At first thought it might be supposed that the simplest way to obtain the pure IZ drop in the rail would be to carry the insulated potential wires close along the web of the rail, and thence, by a twisted pair, from the middle. Actual trial, however, showed that the mutual inductance correction in the latter case was not only large, but uncertain, being practically beyond computation. By placing the potential leads in the form of a rectangle, as shown in Fig. K, Appendix III, the mutual inductance correction was rendered definite and susceptible of computation. By suitably selecting the sides of the rectangle, the resulting mutual-inductance correction can, by trial, be made small. The potential leads were then maintained permanently in this position during the progress of the work. The principal formula for deriving the correction is worked out in Appendix III.

Any error made in the mutual-inductance correction would clearly not affect the skin-effect resistance ratio R'/R, but would affect the values of the inductance L'. The effect of the error would be to alter the value of L' by a constant quantity throughout. If only the changes in L' with frequency and current are studied, such an error becomes eliminated. It was thought desirable in this research to determine the correction (Appendix III), so as to arrive at the best available values for L'.

Corrections for Temperature.—As has already been mentioned, the temperature of the rails tested was appreciably raised when the rail current exceeded 100 ampères, and even with short applications of 750 ampères the rail temperature was frequently raised 20° C. The resistivity temperature coefficient of the steel forming the rail was in each case measured by taking a series of continuous-current rail-resistance measurements, by potenti-

TABLE I.

Data Concerning Steel Rails Tested.

Rail Number / Type		96A P.R.R. standard track	100 N.Y. N.H. & H. standard track	163 A.R.A. type A. track	175 N.Y.C. R.R. standard track	161 A.R.A. type B. track	162 A.R.A. type B. track	170 A.R.A. type A. track	600 A. S.C.E. standard track	174 track	-51 A S.C.E. standard track	702 N.Y.C. R.R. standard contact	871 type D. contact
Linear mass	lbs./yard	100	100	100	100	100	90	90	60	70	80	69.3	86.5
	kg./m.	50	50	50	50	50	45	45	30	35	40	34.6	43.3
Cross-sectional area	sq. in.	9.8	9.8	9.8	9.8	9.8	8.8	8.8	5.88	6.86	7.84	6.79	8.48
	sq. cm.	63.2	63.2	63.2	63.2	63.2	56.9	56.9	37.9	44.3	50.5	43.8	54.6
Perimeter of cross-section	in.	22.6	24.4	24.3	24.4	23.0	21.5	22.7	18.8	18.7	21.7	15.2	21.0
	cm.	57.4	62.0	61.7	62.0	58.4	54.6	57.5	47.8	47.5	55.1	38.6	53.4
Approximate relative distribution of sectional area	head	0.41	0.41	0.37	0.44	0.40	0.40	0.36	0.41	0.41	0.42	0.4	0.34
	web	0.19	0.24	0.23	0.26	0.19	0.19	0.24	0.23	0.18	0.21	0.2	0.11
	base	0.40	0.35	0.40	0.30	0.41	0.41	0.40	0.36	0.40	0.37	0.4	0.55
Length of rail between potential contact points	ft.	30	30	30	30	30	30	30	30	30	30	30	30
	cm.	914	914	914	914	914	914	914	914	914	914	914	914
Resistance of tested length to continuous currents at 20° C. microhms		305.6	319.2	322.3	312.3	223.9	329.7	334.0	428.8	420.5	367.7	281.2	230.5
Resistivity at 20° C. absohm-cm., ρ_{20}		21100	22100	22300	21600	15500	20500	20800	17800	20350	20300	13500	14300
Temperature coefficient of resistivity at 20° C., α_{20}		0.00329	0.00274	0.00272	0.00265	0.00391	0.00356	0.00321	0.00350	0.00345	0.00295	0.00474	0.00458
Maximum skin effect resistance ratio R'/R	V_{60}	9.25	9.0	9.0	9.0	15.65	9.5	8.6	9.1	9.17	8.25	16.35	22.0
	V_{25}	6.08	5.65	5.65	5.65	10.10	6.1	5.6	5.85	6.05	5.35	10.92	13.4
Ratio, $\frac{V_{60}}{V_{25}}$		1.52	1.59	1.59	1.59	1.55	1.56	1.54	1.56	1.51	1.54	1.50	1.64
Square root of ratio of actual test frequencies		1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
Effective area of cross-section at maximum skin effect, square centimetres	S_{60}	6.83	7.02	7.02	7.02	4.04	6.0	6.6	4.2	4.85	6.1	2.7	2.48
	S_{25}	10.4	11.2	11.2	11.2	6.26	9.3	10.2	6.5	7.35	9.45	4.0	4.07
Effective depth of penetration in mm. at maximum skin effect	S_{60}	1.2	1.1	1.1	1.1	0.7	1.1	1.15	0.9	1.0	1.1	0.7	0.47
	S_{25}	1.8	1.8	1.8	1.8	1.07	1.7	1.75	1.35	1.55	1.7	1.04	0.76
Observed r. m. s. current in rail at maximum skin effect, ampères	I_{60}	700	800	800	800	390	600	700	450	505	850	280	160
	I_{25}	750	800	800	800	380	670	700	480	540	800	270	140
Computed mean corresponding magnetic intensity around perimeter	H_{60}	15.3	16.2	16.3	16.2	8.4	13.8	14.15	11.8	13.75	19.4	9.1	3.76
	H_{25}	16.4	16.2	16.3	16.2	8.2	15.4	14.15	12.6	14.5	18.2	8.8	3.30
Permeameter μ max.		....	480	....	432	970	....	....	....	....	....	....	2535
at H		....	16.0	....	16.2	7.5	....	....	....	....	....	....	2.9
Computed skin-effect resistance ratio R'/R	V_{60}	....	7.48	....	7.01	12.12	....	....	....	....	....	....	21.62
	V_{25}	....	4.83	....	4.53	7.83	....	....	....	....	....	....	13.62

TABLE II.

Observations on and Results for Sample Rail No. 174, Maryland Steel Company, April 27, 1915.

Cross-section 6.86 sq. in. (44.3 sq. cm.) 70 pounds per yard (35 kg. per m.) Test frequency 60 ∾.

	Moving coil across strip		Moving coil across rail							
Rail temperature, ° C.	Deflection, D_S, cm.	Capacitance in series, microfarad	Deflection, D_R, cm.	Capacitance in series, microfarad	Deflection, D_X cm.	Total resistance in series, including M (ohms)	Rail current, r. m. s. ampères	Alternating-current rail resistance, R'_{20} microhms	$\frac{R'_{20}}{R_{20}}$	Total rail inductance, millihenrys
33.5	43.68	0.0804	45.98	0.0200	43.42	214900	767.5	3775	8.98	0.01622
38.5	44.72	0.0905	46.03	0.0220	46.22	182400	732.5	3714	8.84	0.01609
40.7	42.80	0.1002	46.10	0.0250	42.92	171400	680.0	3762	8.95	0.01625
39.7	41.93	0.1202	45.52	0.0301	39.95	151400	615.4	3788	9.01	0.01635
37.8	43.92	0.1505	44.77	0.0351	40.60	125000	562.6	3841	9.14	0.01639
35.2	47.23	0.2008	41.15	0.0402	41.00	100100	505.2	3857	9.17	0.01646
32.9	43.05	0.2208	42.28	0.0503	42.25	80060	459.8	3838	9.13	0.01637
30.0	42.30	0.2711	46.68	0.0703	44.83	60060	411.2	3830	9.11	0.01629
26.7	43.60	0.3529	41.07	0.0804	42.78	50060	366.2	3762	8.94	0.01633
11.9	45.33	0.0604	47.47	0.0503	42.57	100100	302.0	3593	8.55	0.01600
13.3	41.23	0.0804	47.72	0.0804	40.87	70060	249.7	3292	7.83	0.01586
13.7	44.08	0.1303	44.78	0.1303	45.65	40060	202.6	2775	6.83	0.01526
14.0	41.57	0.2220	42.57	0.2723	44.02	22060	150.7	2363	5.60	0.01464
14.0	43.98	0.6038	45.40	0.9060	39.10	9060	94.1	1865	4.43	0.01375
0	I	II	III	IV	V	VI	VII	VIII	IX	X

The temperature of the rail during the test varied from 40° C. with the high currents to 12° C. with the low currents. The direct-current resistance of this rail at 20° C. was found, by potentiometer, to be 420.5 microhms = 14.02 microhms per foot = 46 microhms per metre, corresponding to a resistivity of 20,350 absohm-cm.; and the temperature coefficient of resistivity, from and at 20° C., is 0.00345 per degree C.

ometer, at different observed temperatures. The mean values of the temperature coefficient so obtained are indicated in Table I. They range from 0.00265 in the harder steels, to 0.00474 in the soft, higher-conductivity steel of the contact rails. In order to be strictly comparative, the measurements should all be taken with the rails at one and the same temperature of reference, since the skin effect varies appreciably with the resistivity. Since, however, it was not practicable to keep the rails at such a reference temperature, either on different days or with different current-strengths on the same day, the observed rail resistances R' have all been reduced to the reference temperature of 20° C. by means of the ordinarily used formula:

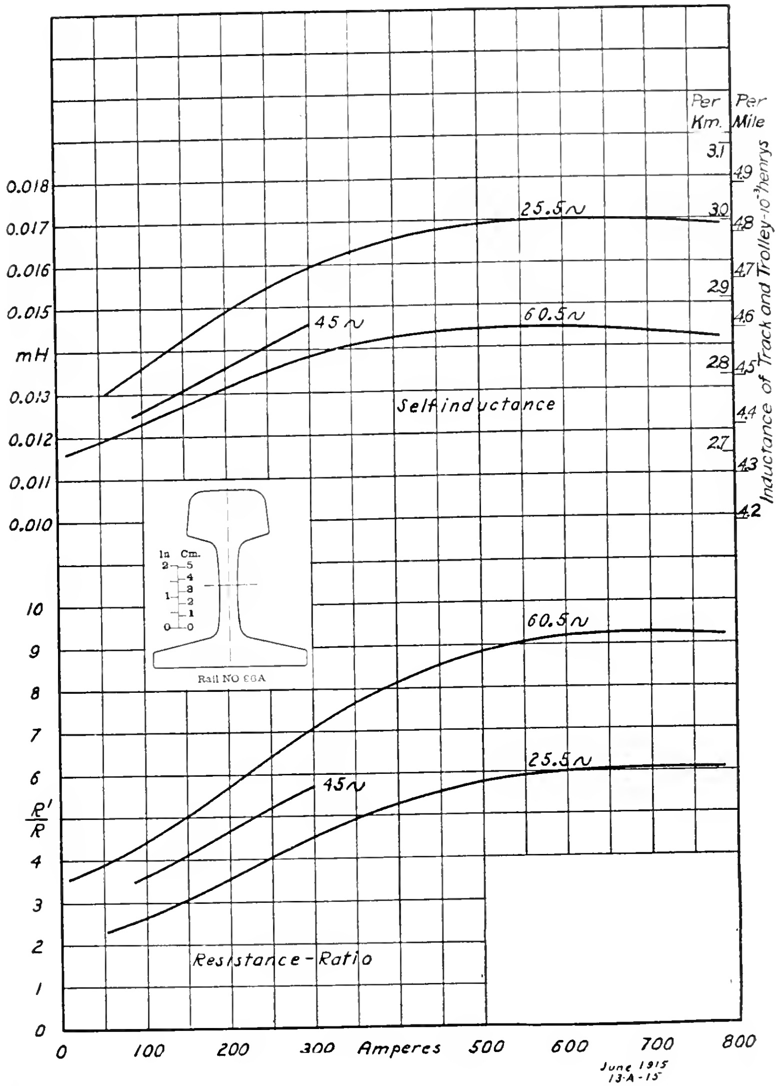
$$R'_{20} = R'_T / \left\{ 1 + \alpha_{20} \left(T - 20 \right) \right\} \qquad \text{ohms (1)}$$

where T was the rail temperature in degrees Centigrade at the time of the test, and α_{20}, the resistivity temperature coefficient as found for this reference temperature. The results thus reduced were found to be fairly consistent, although the full temperature correction, including skin-effect variation, would be much more complicated.

Discussion of Results.—Table II gives a sample set of observations on one rail, taken by the Sumpner dynamometer method. The fixed coils of the dynamometer were conducted to the manganin shunt throughout the test, in the manner indicated in Fig. E. The flux quadrature compensation was adjusted for each alternating-current strength, in the manner described in Appendix I. Column I gives the full double deflection in scale cm. between + and –. The temperature of the rail during the test varied from 40° C. with the high currents, to 12° C. with the low currents. The direct-current resistance of this rail at 20° C. was found, by potentiometer, to be 420.5 microhms = 14.02 microhms per foot = 46 microhms per metre, corresponding to a resistivity of 20,350 absohm-cm.; and the temperature coefficient of resistivity, from and at 20° C., is 0.00345 per degree C.

Column X gives the total self-inductance of 30 feet (9.14 metres) of the rail in millihenrys. This is the inferred self-inductance to infinity, on the assumption that it includes all of the internal and external flux linked with the rail and due to the rail current in a rectangle based on 30 feet (9.14 metres) between potential points and extending radially to infinity.

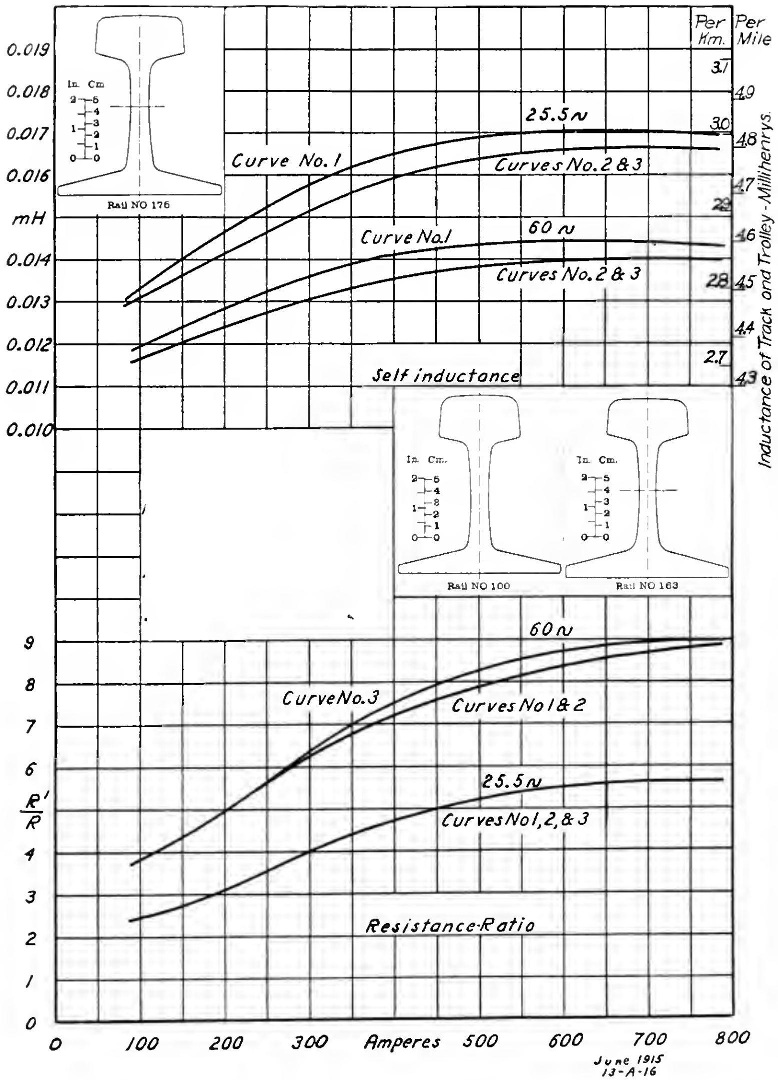
FIG. 5.



Curves of resistance-ratio and self-inductance rail No. 95-A. Study of skin effect in steel rails.

The results of the observations are presented in Figs. 5 to 10 inclusive. In all of these figures the abscissas are in r. m. s. ampères flowing through the rail under test. There are two sets of ordinates. The lower set is in each figure the skin-effect

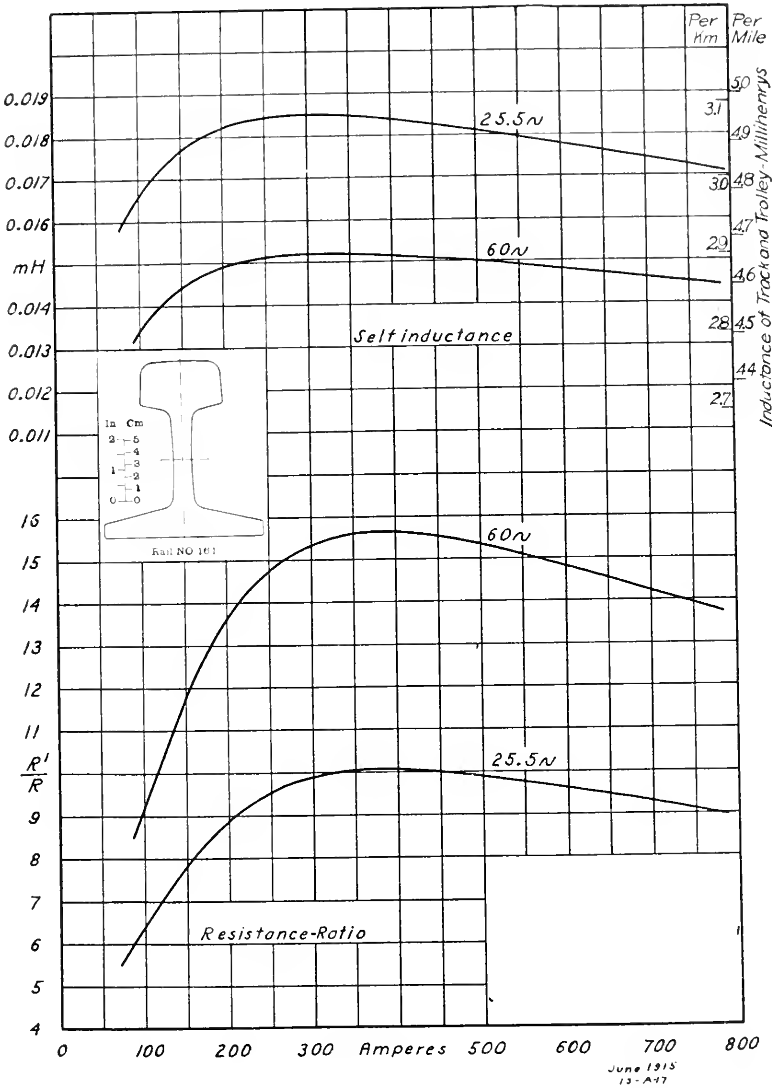
FIG. 6.



Curves of resistance-ratio and self-inductance. Rail No. 100, curve No. 1. Rail No. 163, curve No. 2. Rail No. 175, curve No. 3. Study of skin effect in steel rails.

resistance ratio R'/R; or the ratio of the apparent resistance of the rail in the presence of skin effect (reduced to 20° C.) to the resistance which it offers to continuous current from a storage battery at 20° C. The upper set of ordinates gives the inductance of the

FIG. 7.

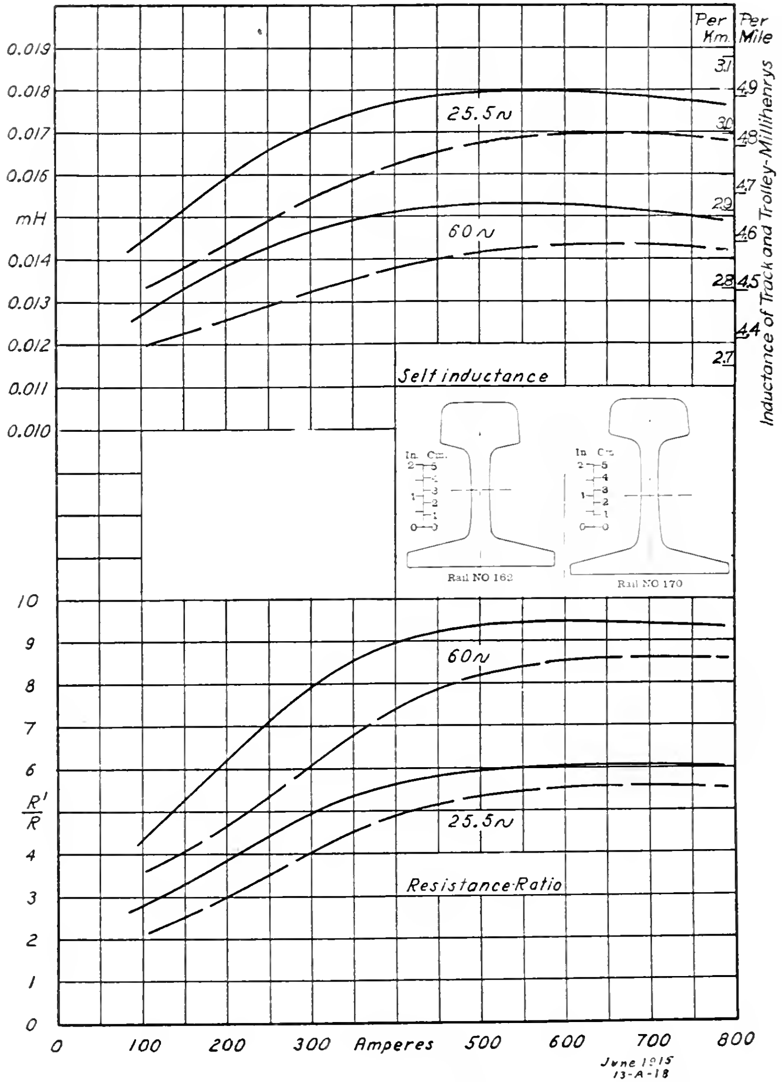


Curves of resistance-ratio and self-inductance. Rail No. 161. Study of skin effect in steel rails.

rail between contact points (914 cm.) in millihenrys, as referred to infinite flux radius. The total linear inductance of the rail L_1' is obtainable from these values by dividing with 914.

It will be seen that the skin-effect resistance ratio R'/R com-

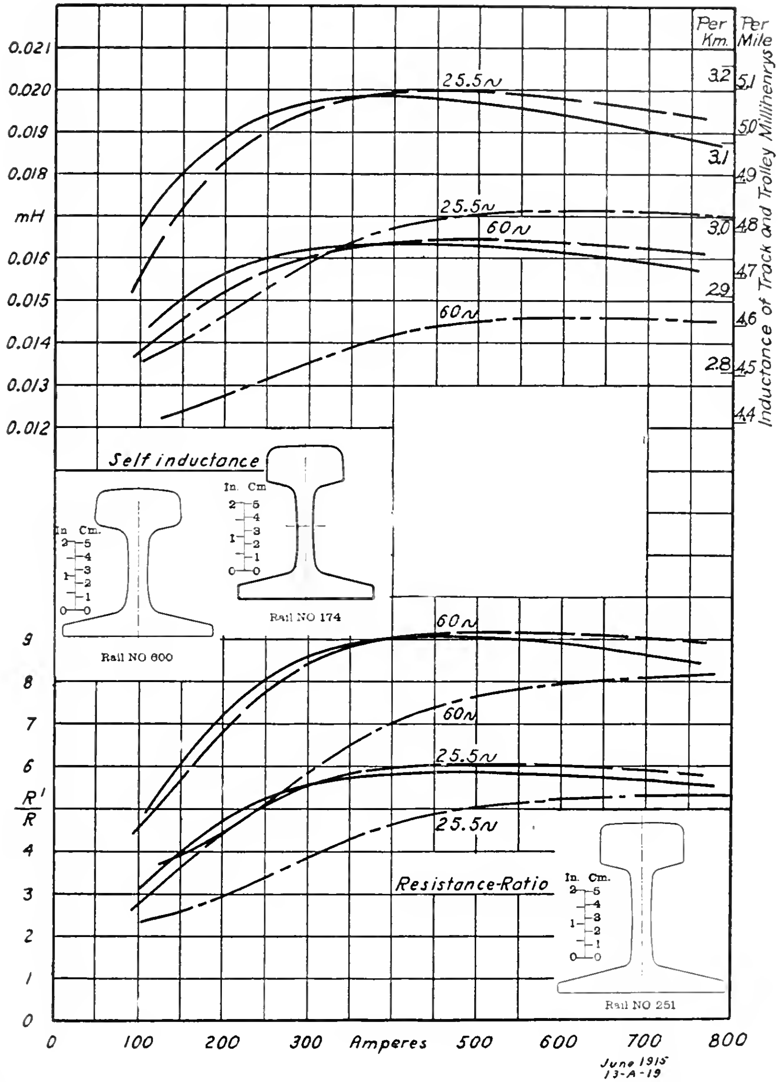
FIG. 8.



Curves of resistance-ratio and self-inductance. Rail No. 162 ——. Rail No. 170 — —.
Study of skin effect in steel rails.

mences with feeble rail current, at a relatively low value, increases when the current is increased, and, in nearly all cases, reaches a maximum value within the limits of 800 r. m. s. ampères. Similar remarks apply to the rail inductance L_1'. The skin-effect

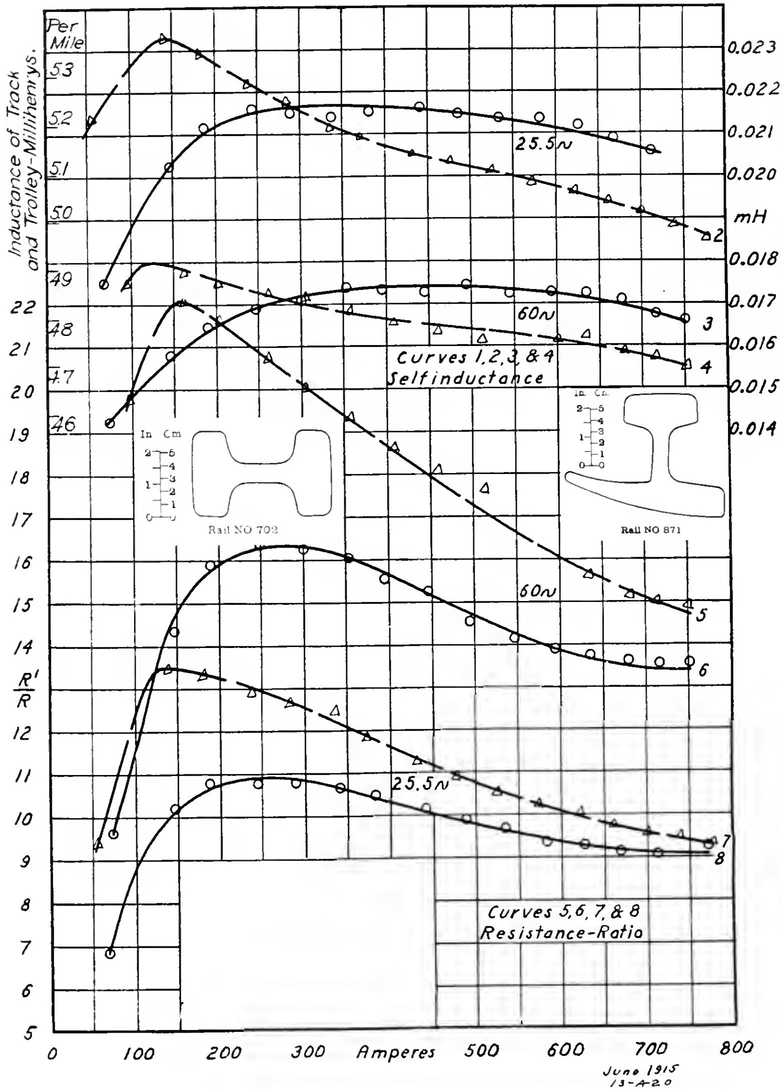
FIG. 9.



Curves of resistance-ratio and self-inductance. Rail No. 600 ———. Rail No. 174 ——. Rail No. 251 — — —. Study of skin effect in steel rails.

resistance ratio is greater at 60 ∾ than at 25 ∾, as might be expected; whereas the rail inductance L_1' is greater at 25 ∾ than at 60 ∾, although the rail reactance $L_1'\omega$ would always be greater at 60 ∾ than at 25 ∾.

FIG. 10.



Curves of resistance-ratio and self-inductance. Rail No. 702 -o———o-. Rail No. 871 -Δ— —Δ-.
Study of skin effect in steel rails.

The rise of skin-effect resistance to a maximum at a certain value of the rail current, is attributable to the variable permeability of the steel, which reaches a maximum at a certain value of the magnetizing force H, depending on the magnetic quality

of the steel, the effective skin penetration depth being changed accordingly. This phenomenon of a maximum impedance in steel prisms to a particular current-strength has been known experimentally at least as far back as 1893.*

Fig. 10 shows the resistance ratios and inductances of two soft steel contact rails. It will be noticed that the resistance ratio of No. 871 rises to 22; *i.e.*, that its alternating-current linear resistance at 60 ∾ is 22 times its direct-current resistance at the same temperature (20° C.). At 25.5 ∾, the resistance ratio of this rail is 13.5. Not only are these resistance ratios relatively large, but they occur at relatively small rail currents (150 r. m. s. ampères) and corresponding values of H at the perimeter (3 gilberts/cm.). This is attributable to the relatively large values of conductivity (7×10^{-5} abmho/cm.) and permeability (2500 gausses per gilbert/cm.). The equivalent penetration depth of the alternating current at this maximum permeability and at 25.5 ∾ is only 0.076 cm.; so that very little of the steel is utilized electrically.

On the upper right hand of each figure is the computed scale of linear inductance of the trolley wire and one track as deduced in Appendix II. The linear inductance of the system exceeds in one case 5 millihenrys per mile.

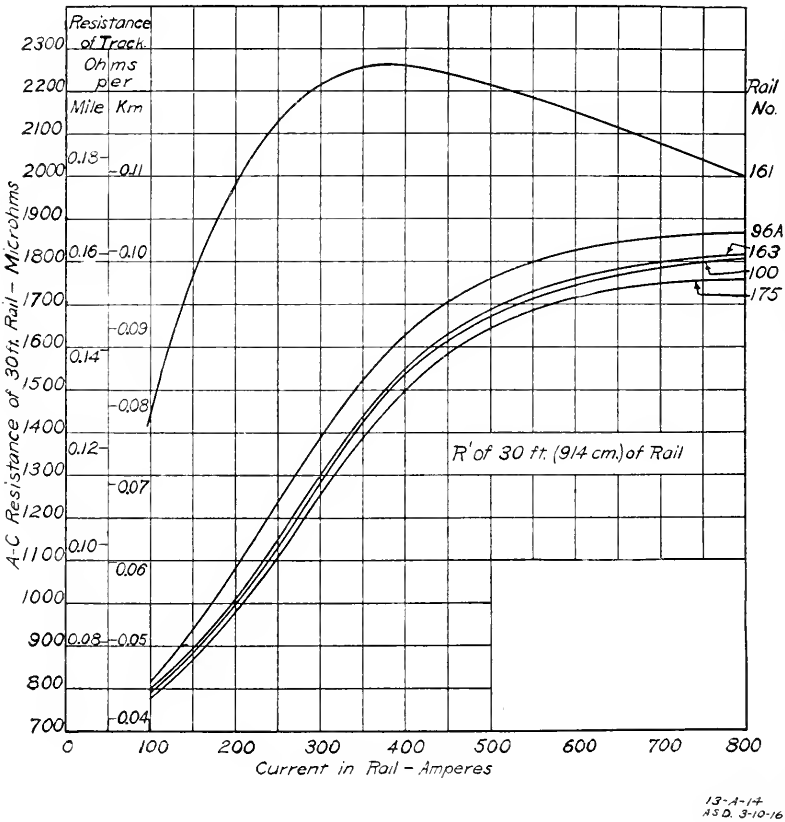
Fig. 11 shows the total alternating-current resistance R' in 30 feet (914 cm.) of each of the track rails at 25.5 ∾ to the scale of microhms ordinates. The scale is also repeated in ohms per mile and ohms per kilometre of a track of two rails in parallel, assuming perfect bonding but no copper reënforcement, also negligible leakance to ground. It will be observed that rail No. 161 has a higher linear resistance than any of the others, in spite of the fact that its conductivity is relatively high. The high alternating-current resistance is attributable to a small equivalent penetration depth ($\delta = 0.107$ cm. at 25.5 ∾), which in turn is due to the large product of γ and μ. To direct currents, this rail would offer the lowest resistance among all the track rails tested.

It is shown in Appendix IV that the resistance-ratio R'/R for a rail can be deduced from the measured direct-current values of its conductivity γ and permeability μ, for any assigned frequency, subject to a certain range of inaccuracy due to errors of permeability and shape, the actual effective alternating-current permeability dif-

* Bibliography No. 2.

fering to some extent from that observed by direct-current permeameter, and the shape of the rail involving edge effects owing to departure from a simple cylinder. The permeability and shape correction factors which must be applied to the computed values of R'/R, in order to arrive at the actual values, are at present

FIG. 11.

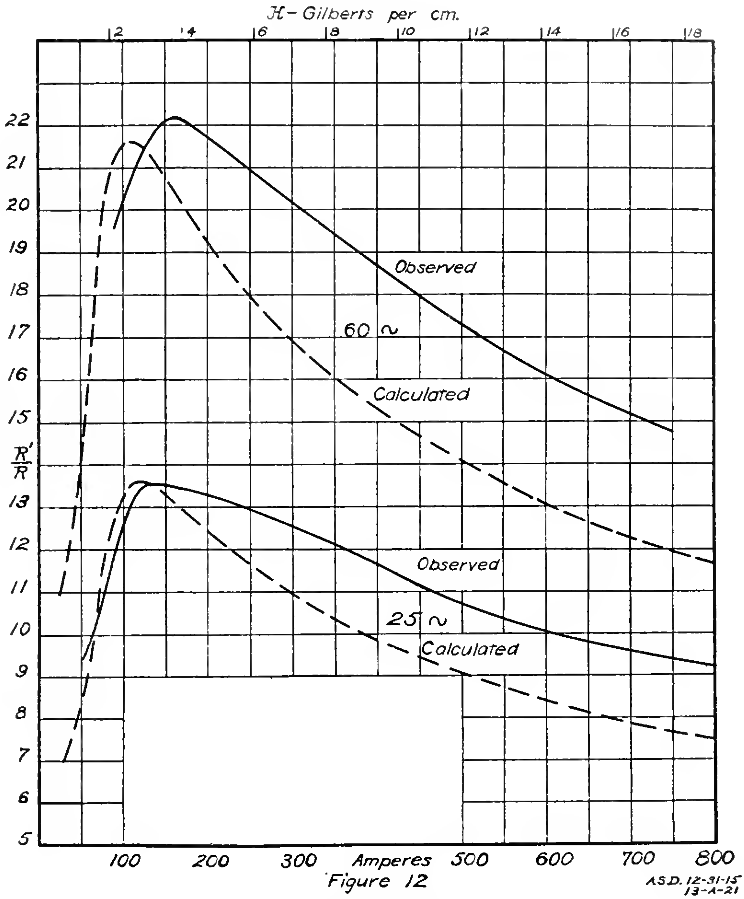


Comparison of R′ at 25.5 ∾. Rails number 161, 96A, 163, 190, 175. Study of skin effect in steel rails.

beyond direct calculation, but may be estimated from experimental observations. Thus, in Fig. 12, the observed and computed values of R'/R are given for the contact rail No. 871 at the two test frequencies 60 ∾ and 25 ∾. The computed values are obtained by (65), from measured direct-current conductivity γ and direct-current permeameter μ of a rod 38 cm. (15 inches)

long and 1.25 cm. (0.49 inch) in diameter cut from the head of this rail. It will be seen that, at or near 150 ampères r. m. s., the observed values of R'/R reach a maximum, and are in fairly close agreement with the calculated values; so that the correction factor

FIG. 12.

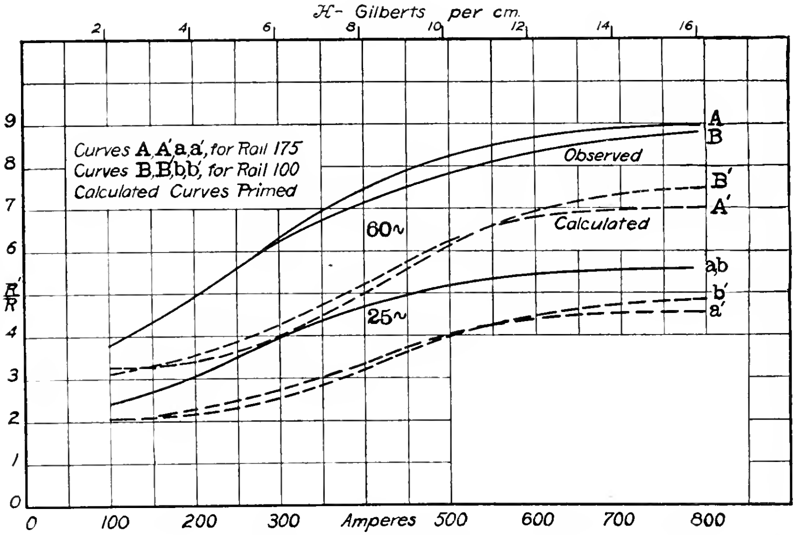


Rail 871. Curves of resistance ratio calculated from infinite strip formula and] D-C values of permeability. Study of skin effect in steel rails.

for 25 ∾ and 125 ampères is 1.0. At higher current-strengths, however, the observed resistance ratio rises above the computed resistance ratio and the correction factor becomes greater than unity. For 750 ampères of rail current at 60 ∾, it is 14.8/12 =

1.233, and at 25 ∾ it is 9.38/7.65 = 1.23. For this rail with its particular values of conductivity and permeability, the correction factor varies between 0.9 and 1.23, according to the strength of current. Since the resistance ratio R'/R is a maximum for that current-strength and value of H at which the effective permeability is a maximum, it is ordinarily of greater importance to determine the correction factor at this maximum point, as it is likely to be the condition of greatest power loss in practice.

FIG. 13.

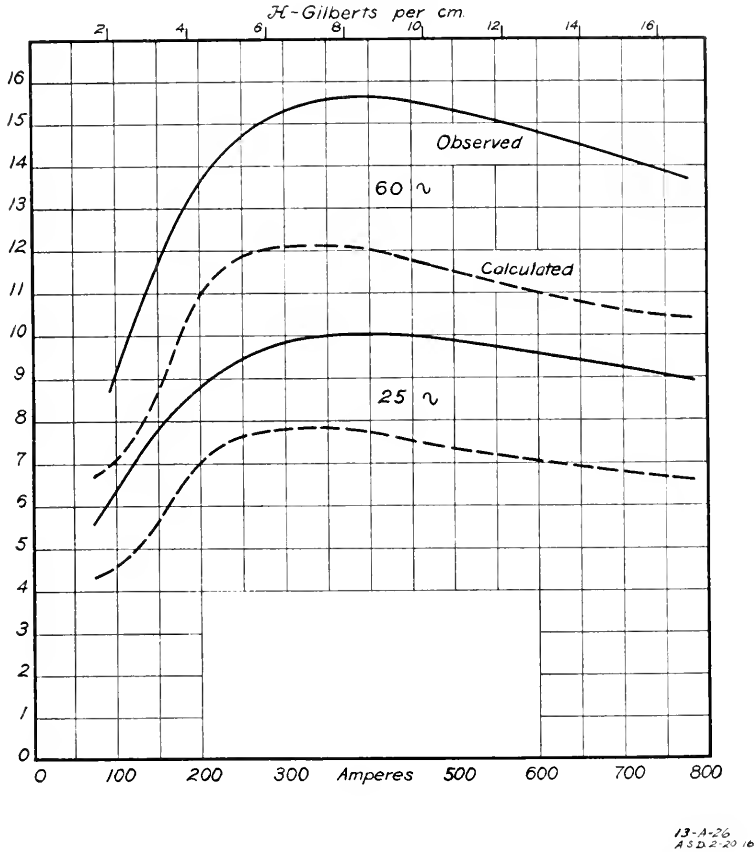


Curves of resistance ratio calculated from infinite strip formula and D-C values of permeability. Study of skin effect in steel rails.

Fig. 13 shows corresponding curves of observed and computed resistance ratios for low-permeability track rails 175 and 100, at 60 ∾ and 25 ∾. Here the maximum values are not exceeded at the maximum current of 800 ampères, and the correction factor is appreciably over 1.0 throughout. Thus on rail 175, at 60 ∾, this factor is 1.23 at 100 ampères, and attains 1.47 at 350 ampères. At 25 ∾, the maximum value of the correction factor is 1.45 at 350 ampères. The samples of steel from which the calculated values were obtained were rods cut from both sides of the head and also from the flange. The values of γ and μ obtained in rods from these different positions in the section of one and the same rail were found to be in satisfactory agreement.

Fig. 14 shows corresponding curves of observed and computed resistance ratios for the medium-permeability track rail No. 161. Here the maximum ratios are reached near to 350 ampères. The maxima of the computed curves agree fairly well with the maxima of the observed curves, and this is a property found in all of the

FIG. 14.



Rail 161 curves of resistance ratio calculated from infinite strip formula and D-C values of permeability. Study of skin effect in steel rails.

cases investigated. The correction factor for 400 ampères and 60 ∾ is $15.6/12.1 = 1.30$, and at 25 ∾ it is $10.05/7.75 = 1.30$. The computed values in this case were obtained from observations of γ and μ on one rod 38 cm. long and 1.25 cm. in diameter, cut from the head of the rail.

Measurements of Conductivity.—The sample steel rod was milled from the rail and then turned in the lathe. It was finally finished to the required diameter (1.25 cm.) by filing in the lathe. The conductivity of this rod was determined at a series of different temperatures between 10° C. and 25° C., by direct-current potentiometer measurement, using such strengths of storage-battery current as served to bring the temperature of the rod up to the required amount. Both the resistivity and its temperature coefficient found in this way agreed satisfactorily with the values obtained previously in the rail tests as already described.

Measurements of Permeability.—The sample steel rod from the rail under investigation was tested in a Burrows permeameter,* which gave satisfactory results. In one case the 38-cm. rod, after being tested in this permeameter, was cut down in the lathe to a diameter of 0.6 cm. and tested in a Koepsel permeameter.† The permeability of the material as obtained from the Koepsel permeameter was a few per cent. less throughout than that obtained in the Burrows permeameter, which difference might be attributed to the relatively greater effect of hardening machine treatment on the sample of smaller diameter. It should be observed from formula (65) that 1 per cent. error in the measurement of permeability only affects the resistance ratio R'/R by 0.5 per cent.

Technic Recommended for Predetermining Rail Resistance Ratios.—According to the results here reported, it is sufficient for the determination of the maximum skin-effect resistance ratio R'/R in a steel rail to measure the values of γ and μ in a sample rod of the same material, which, by formula (65), gives the computed value of R'/R for a given frequency and series of alternating-current rail-current strengths, assuming that the measured direct-current permeabilities do not appreciably differ from the actual effective alternating-current permeabilities at these currents, including the effects of hysteresis, and also that the rail has a simple circular or cylindrical cross-section. In order, then, to correct for the errors of permeability and shape, a correction factor should be applied to the computed ratio. This correction factor appears in the results here reported to have varied in track rails, at maximum permeability, from 1.2 to 1.3. It is probably advisable to use the latter value for security. In other words, the

* Bibliography No. 18.

† Bibliography No. 30.

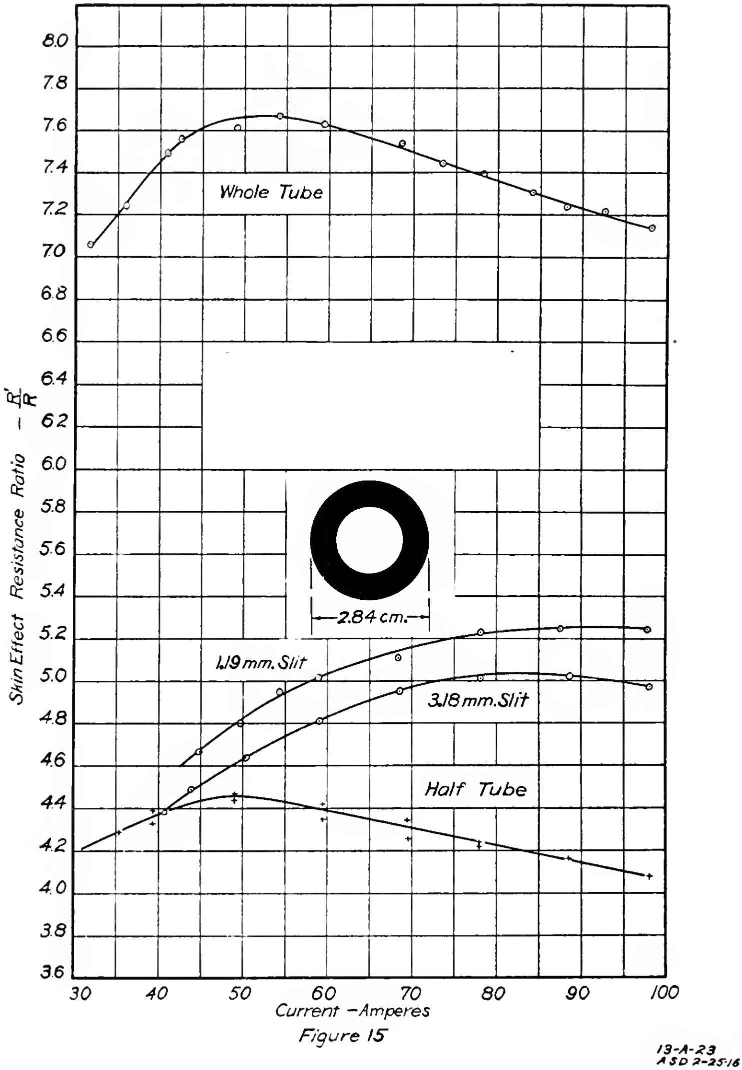
computed value of R'/R should be increased by 30 per cent. for the unknown permeability and shape errors. The result may then be taken as the maximum skin-effect resistance ratio of the rail, at the temperature and frequency considered. At all other rail currents, the resistance-ratio and the resistance per kilometre will be less, at constant rail temperature.

Best Shape of Rail Section for Conducting Purposes.—In steel track rails, mechanical considerations are necessarily paramount for determining the shape of the cross-section. For conducting rails, however, where the stresses to be supported are much smaller, consideration may well be given to the best form of cross-section for conducting purposes. Formula (68) shows that, provided there is sufficient depth beneath the surface in which the electric and magnetic fluxes can deploy—say, 4δ for a single surface of slab, or 8δ between opposite surfaces of a strap—the effective alternating-current conductance, in the presence of skin effect, depends upon the ratio P/S, or the perimeter per square centimetre of cross-section. This would point to the use of a flat strap as the best type of conductor. The edge effect in such a strap, however, militates against its use, to say nothing of its clumsiness and oxidizability. For these reasons it is preferable to employ a steel tube or hollow cylinder. In practice, in order to improve the mechanical brush-contact surface, the tube should be flattened, at least on the contact side, and sharp edges in the contour avoided. If the section is simply tubular, of thickness exceeding 4δ cm., the interior surface of the tube is prevented from carrying any appreciable alternating current. By slitting the tube, however, or by rolling a plate into the form of a nearly closed box beam, 8δ or more in wall thickness, both the internal and external surfaces of the hollow conductor become available.

To test this plan, a steel tube was employed 150 cm. long and of the cross-section shown in Fig. 15. The resistance ratio of this tube was found to be 7.66, for 60 $\sim$, at 53 ampères r. m. s.* When a thin, longitudinal slit (1.19 mm. wide) was milled along this tube, the resistance ratio fell to 5.26, with the maximum at about 90 ampères. When the slot was widened to 3.18 mm., the ratio was observed to fall to 5.04 at 80 ampères. When the tube

* The resistance ratio computed by formula (65), from a sample rod of this steel, had a maximum at 53 ampères of only 6.45, representing a correction factor of 1.18 for hysteresis and permeability alone.

FIG. 15.



Skin effect resistance ratio for steel tube at 60 ∾. Outside diam. 2.84 cm.—6.35mm. wall.

was cut in half, by making an opposite longitudinal slot, the value fell to 4.46 at 48 ampères. The values of current at which the maxima are obtained correspond very fairly with the reciprocals of the effective perimeters in each case. Inserting the slot did not

double the effective alternating-current conductance, but did increase it in the ratio of $7.66/5.04 = 1.52$, the discrepancy being presumably attributable to magnetic leakage near or across the slit. It would appear, therefore, that the two half tubes, connected in parallel, would be a better joint conductor than the slotted tube, and would exceed the conductance of the unslotted tube in the ratio $7.66/4.46 = 1.72$.

It is hoped to investigate further this question of most economical conducting cross-section.

It should be pointed out that for a given shape of cross-section the effective alternating-current conductance of a rail depends upon both γ and μ, and not merely on one of these quantities. An increase in permeability may more than offset the advantage of an increase in conductivity γ. An ideal steel would have a very high conductivity associated with a very low permeability.

Chemical Analysis of Samples.—Table III gives the chemical analysis of the steel in the various rails tested.

TABLE III.

Chemical Contents of Rails Used in the Research on Skin Effect in Steel Rails.

Rail No.	Percentage Element C	P	Si	Mn	Cr	Ni	S
* 96A	0.65	0.090	0.06	0.68	0.35	0.55	0.065
*100	0.55	0.090	0.08	1.08	0.30	0.60	0.095
*163	0.70		0.07	0.97	0.47	0.46	0.05
*175	0.60	0.124	0.08	0.83	0.30	0.45	0.07
*161-1	0.42	0.004	0.04	0.50	0.05	0.15	0.08
*161-2	0.68		0.09	0.65	0.31	0.51	0.095
*162	0.38	0.032	0.06	0.62	0.31	0.40	0.05
*170	0.40	0.004	0.05	0.43	0.085	0.12	0.04
600	0.59	0.032	0.122	0.67			0.044
174	0.37	0.065	0.032	0.40			0.070
251	0.74	0.035	0.063	0.34			0.072
702	0.11	0.113	0.020	0.36			0.091
871	0.17	0.132	0.025	0.51			0.099

* These tests were made by students in chemistry and are not equally reliable.

In conclusion, the authors desire to express their indebtedness to the courtesy of the Lackawanna Steel Company and the Maryland Steel Company for the use of the steel rails tested, also to Dr. G. A. Campbell for valuable suggestions on the manuscript.

SUMMARY OF CONCLUSIONS.

1. The maximum observed skin-effect resistance ratio among ten track rails, at 25 ∾, varied between 5.35 and 10.1, and in two contact rails between 10.92 and 13.4.

2. The maximum observed skin-effect resistance ratio was found to vary substantially as the square root of the impressed frequency between the limits of 25 ∾ and 60 ∾.

3. The effective skin depth of alternating-current penetration, at 25 ∾, among all the twelve rails tested, varied between 0.76 mm. and 1.8 mm.

4. The values of the mean superficial r. m. s. magnetic intensity H at which the maximum skin effect developed, were between the limits of 3.3 and 16.4 gilberts per centimetre. These were but little influenced by frequency, and were in good agreement with the values of H for maximum μ, as obtained by direct-current permeameter.

5. The best workshop method of measuring the skin effect in track rails was, in this case, found to be based on the use of a particular form of dynamometer.

6. The effective alternating-current conductance of a rail is, to a first approximation, inversely as the square root of the frequency, and, at a given frequency, is directly proportional to the perimeter, and to the square root of the ratio $\frac{\gamma}{\mu}$.

7. It is therefore, in general, useless to increase the conductivity γ of the steel in a rail if the permeability μ is thereby increased in the same or a greater ratio.

8. From the results here reported, it would seem that the skin-effect resistance ratio of a rail, to a given alternating-current frequency and current-strength, can be approximately predetermined from measurements of the conductivity γ and permeability μ of the steel, by applying an experimentally determined factor to cover edge effect and other discrepancies. This factor, which may be called the "edge-effect coefficient," appeared to be not more than 1.3 at the maximum skin-effect ratio.

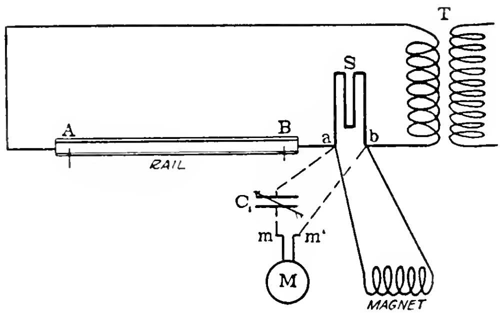
9. The best form of rail for current-carrying capacity should be one in which the effective perimeter is a maximum while allowing sufficient depth of surface. Among the worst forms are probably a thick solid prism and a cylinder. A hollow cylinder may be greatly improved by slitting it, so as to admit current to its interior surface.

APPENDIX I.

METHOD OF EMPLOYING THE SUMPNER DYNAMOMETER IN IMPEDANCE MEASUREMENTS.

The Sumpner dynamometer had one fixed coil A with 4000 turns of relatively fine insulated wire having 90 ohms resistance, and another fixed coil C, with 200 turns of coarser wire, having about 0.75 ohm resistance. The moving coil M has about 50 turns with about 60 ohms resistance, including leads and suspension. The fixed coils being provided with a laminated iron core, the moving coil swings in a relatively strong magnetic field, due to the mmf. of the fixed coils.

FIG. A.



Sumpner-dynamometer test connections.

Fig. A indicates the connections employed with the instrument connected across the manganin strip S to measure the p. d. across the terminals a, b, and therefore the current in the rail circuit. The current flowing through the magnet coils from the terminals a, b, under the impressed voltage $E_s = IS$, may be assumed, for the present, to produce an alternating magnetic flux in the air-gap, 90° in phase behind E_s. The branch circuit containing the moving coil M includes a small condenser, of pure capacity reactance so large that the resistance and inductive reactance in M are negligible with respect thereto. The current in M will therefore lead the impressed voltage E_s by substantially 90°, and will therefore be in phase with the air-gap flux-density B_s. The moving torque will therefore be

$$\tau_s = kI_{Ms}B_s \qquad \text{dyne perp. cms.*} \quad (2)$$

* Unit torque, in the C. G. S. system, is one dyne acting perpendicularly at a radius of one cm.

where k is a constant for the instrument, which can be determined from the use of a known voltage.

The current in the moving coil will be

$$I_{M_s} = jE_s c_s \omega \qquad \text{ampères}\angle \qquad (3)$$

and the flux density in the air-gap, assumed radial, is

$$B_s = -jk_1E_s/\omega \qquad \text{gausses}\angle \qquad (4)$$

k_1 being a constant for the magnetic circuit of the instrument. Consequently

$$\tau_s = kk_1E_s^2c_s \qquad \text{dyne} \perp \text{cm.} \qquad (5)$$

and if the moving system has a unifilar suspension providing a resisting torque proportional to the scale deflection D cms.,

$$\tau_s = aD_s \qquad \text{dyne} \perp \text{cm.} \qquad (6)$$

where a is a constant depending on the elastic torsion of the suspension and on the scale. Equating the opposing torques,

$$kk_1E_s^2c_s = aD_s \qquad \text{dyne} \perp \text{cm.} \qquad (7)$$

or

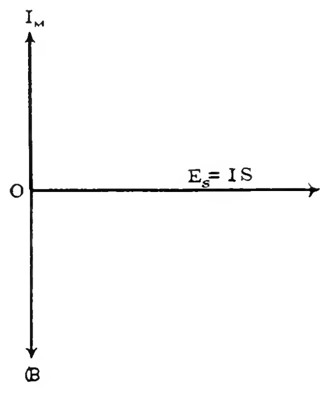
$$E_s = \sqrt{\frac{aD_s}{kk_1c_s}} = K\sqrt{\frac{D_s}{c_s}} \qquad \text{volts} \qquad (8)$$

where $K = \sqrt{\frac{a}{kk_1}}$;
and

$$\frac{D_s}{c_s} = E_s^2 \cdot \frac{1}{K^2} \qquad (9)$$

The vector diagram of the case is presented in Fig. (B). OE_s is the alternating-current r. m. s. voltage across the terminals ab of

FIG. B.

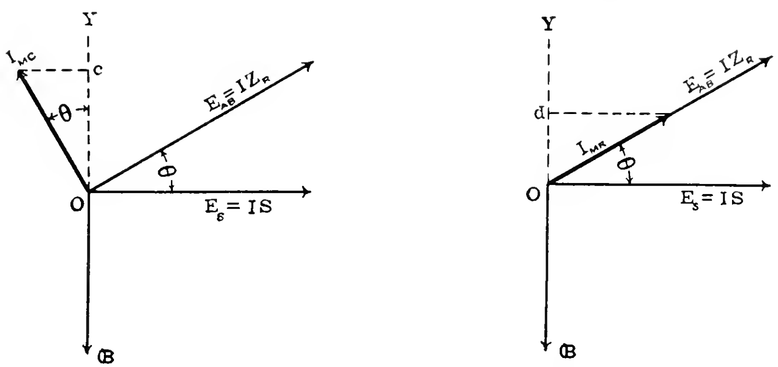


Vector diagram of Sumpner-dynamometer phase relations.

the shunt, taken as at standard phase. OB is the flux density in the air-gap, assumed to be just 90° behind OE_s. OI_m represents the current in the moving coil M, advanced 90° ahead OE_s, by reason of the capacity reactance in its branch circuit.

If now the terminals mm' of the moving coil are transferred to the potential terminals AB of the rail, the flux density in the air-gap remains the same as before; but the current in the moving coil

FIG. C. FIG. D.



Vector diagram of Sumpner-dynamometer phase relations.

is changed, both in magnitude and phase. Referring to Fig. C, let OE_{AB} be the vector voltage on the rail, advanced $\theta°$ ahead of the current I, according to the relation

$$E_{AB} = IZ\underline{/\theta} = I(R' + jL'\omega) \qquad \text{volts}\angle \qquad (10)$$

The current in the moving coil OI_{MC} will be thrown 90° ahead of OE_{AB} owing to the presence of the condenser c_R in its circuit. The torque will then be

$$\tau_R = kI_{MC} \cos\theta . B_s \qquad \text{dynes T cm.} \qquad (11)$$

$$= kE_{AB}c_R\,\omega \cos\theta . k_1E_s/\omega$$

$$= kk_1E_{AB}E_s \cos\theta\; c_R \qquad \text{dynes T cm.} \qquad (12)$$

or proportional to the product of Oc. OB on the diagram. This torque produces a deflection

$$D_R = \tau_R/a \qquad \text{cm.} \qquad (13)$$

so that

$$\frac{D_R}{c_R} = \frac{kk_1}{a} . E_{AB} . E_s . \cos\theta = E_{AB} . E_s . \cos\theta \frac{1}{K^2} \qquad \frac{\text{cm.}}{\text{farad}} \qquad (14)$$

Dividing (14) by (9), we obtain

$$\frac{D_R}{c_R} \bigg/ \frac{D_s}{c_s} = \frac{E_{AB} . E_s . \cos\theta}{E^2_s} = \frac{E_{AB}\cos\theta}{E_s} = \frac{IR'}{IS} = \frac{R'}{S} \quad \text{numeric} \quad (15)$$

If now a suitable non-reactive resistance R_M ohms is substituted for the condenser C_1 the current which will flow in the moving coil will be

$$I_{MX} = \frac{E_{AB}}{R_M} = \frac{IZ\ \theta}{R_M} \quad \text{ampères}\angle \quad (16)$$

In Fig. D, OE_s is the voltage at standard phase across the shunt S, and OE_{AB} the voltage across the terminals AB leading the current by the angle θ°. Then the current in the moving coil will be in phase with OE_{AB} and is indicated by OI_{MR}. The component Od, on the axis OY, will be $OI_{MR}\sin\theta$, and the torque will be

$$\tau_X = kI_{MX} \sin\theta\, B_s \quad \text{dynes} \perp \text{cm.} \quad (17)$$

$$= kk_1 . \frac{E_{AB}}{R_M} . \sin\theta . \frac{E_s}{\omega} \quad \text{dynes} \perp \text{cm.} \quad (18)$$

$$= aD_X$$

where D_X is the scale deflection in this case.

Equating torques

$$D_X R_M = \frac{1}{K^2} E_{AB} . \sin\theta . \frac{E_s}{\omega} \quad \text{cm-ohms} \quad (19)$$

Dividing (19) by (9), we have

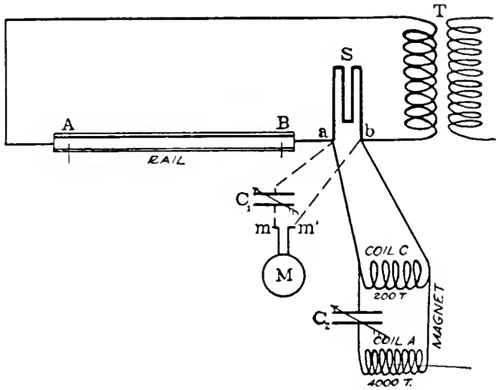
$$\frac{D_X . R_M}{D_s / C_s} = \frac{E_{AB}}{E_s} . \frac{\sin\theta}{\omega} = \frac{L'}{S} \quad \frac{\text{henrys}}{\text{ohms}} \quad (20)$$

It is therefore evident that, assuming the flux in the air-gap to be in quadrature with the voltage impressed on the alternating-current magnet, the quantities I, R', S, and D'/S are found in terms of the three deflections, D_s, D_R, and D_X, and the corresponding impedances in the moving-coil circuits.

In the actual instrument, however, the magnetic flux and flux density B_s are not more than about 85° behind the impressed voltage in phase, as is shown by the fact that a deflection on the scale is produced when the magnet coil and the moving coil are connected in parallel to one and the same voltage E_s. In order to correct for this deviation, and bring the resultant magnetic flux density into strict quadrature with E_s, a condenser C_2 is

inserted in the 4000-turn coil A, as shown in Fig. E. This condenser has from 1 to 6 microfarads capacitance, according to the frequency and to the magnitude of E_s, which affects the hysteresis in the core. Its magnitude is adjusted by trial in such a manner

FIG. E.



Sumpner-dynamometer test connections.

that when the condenser C_1 is replaced by a resistance in Fig. E, no deflection is produced.

APPENDIX II.

THE LINEAR INDUCTANCE OF A SIMPLE SYMMETRICAL ELECTRIC-RAILROAD CONDUCTING SYSTEM, COMPRISING A LONG, STRAIGHT, UNIFORM TROLLEY WIRE, SUPPORTED AT A FIXED HEIGHT ABOVE THE CENTRE OF A TRACK FORMED BY TWO SIMILAR AND PARALLEL STEEL RAILS.

As a first step, the simpler and more familiar case may be considered of a single long trolley wire T (Fig. F) of radius ρ_0 cm., supported at a constant interaxial vertical distance d cm. above the equivalent centre of a single steel rail R. The permeability of the trolley wire is μ_0. The extra linear inductance of the trolley wire—*i.e.*, the inductance per cm., in so far as depends on flux collapsing upon the surface of the wire when its current is brought to zero*—is, by Neumann's formula,

$$L_{0e} = 2\left(\text{logh}\,\frac{2l}{\rho_0} - 1\right) \quad \frac{\text{external abhenrys}}{\text{wire cm.}} \qquad (21)$$

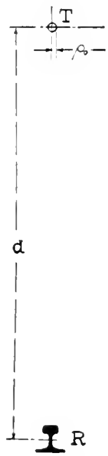
* "The Self and Mutual Inductance of Linear Conductors," by E. B. Rosa, *Bulletin of the Bureau of Standards*, vol. 4, No. 2, p. 301, September, 1907.

where l is the length of the trolley wire in cm., and logh signifies the hyperbolic or Napierian logarithm. This may be written

$$L_{oe} = 2 \operatorname{logh} \frac{2l}{\epsilon\rho_0} \qquad \frac{\text{external abhenrys}}{\text{wire cm.}} \qquad (22)$$

where $\epsilon = 2.718 \ldots$ the Napierian base. The linear internal

FIG. F.



Cross-section of single rail and an overhead trolley wire.

inductance of a round wire of uniform permeability ($\mu_0 = 1$ for copper) is also well known to be

$$L_{0i} = \frac{\mu_0}{2} \qquad \frac{\text{internal abhenrys}}{\text{wire cm.}} \qquad (23)$$

The total linear inductance of the trolley wire, extending outwards to an indefinite distance from its axis, is therefore

$$L_0 = L_{0i} + L_{0e} = 2 \operatorname{logh} \frac{2l}{\epsilon\rho_0} + \frac{\mu_0}{2} \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (24)$$

Moreover, the linear mutual inductance of the trolley wire and the rail, considering the latter as substantially equivalent to a parallel wire of dimensions small compared with the distance l, is*

$$M_{01} = 2\left(\operatorname{logh} \frac{2l}{d} - 1\right) = 2 \operatorname{logh} \frac{2l}{\epsilon d} \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (25)$$

* *Bulletin of the Bureau of Standards*, vol. 4, p. 306.

The linear inductance of the wire in the presence of the rail return conductor becomes, therefore,

$$L_{01} = \frac{\mu_0}{2} + 2\left(\text{logh}\,\frac{2l}{\epsilon\rho_0} - \text{logh}\,\frac{2l}{\epsilon d}\right) \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (26)$$

$$= \frac{\mu_0}{2} + 2\,\text{logh}\,\frac{d}{\rho_0} \qquad \frac{\text{abhenrys}}{\text{wire cm.}} \qquad (27)$$

This trolley-wire linear inductance to rail return can be computed with satisfactory precision, since any error in assigning the equivalent centre of the rail has ordinarily but little effect on the result.

Again, the linear internal inductance of the rail being written L_{1i} abhenrys per cm., the linear external inductance of the rail may be taken as

$$L_{1e} = 2\,\text{logh}\,\frac{2l}{\epsilon\rho_1} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (28)$$

where ρ_1 is the equivalent radius of the rail, and a quantity not easy to assign precisely in practice. The linear total inductance of the rail is then outwards to infinity

$$L_1 = L_{1i} + 2\,\text{logh}\,\frac{2l}{\epsilon\rho_1} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (29)$$

and, taking the mutual inductance to the trolley wire M_{01} of (25) into account, the linear total inductance of the rail in the presence of the return trolley wire is

$$L_{10} = L_{1i} + 2\,\text{logh}\,\frac{d}{\rho_1} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (30)$$

The linear total inductance of the loop formed by trolley wire and rail together is then

$$L = L_{01} + L_{10} = \frac{\mu_0}{2} + L_{1i} + 2\,\text{logh}\,\frac{d}{\rho_0} + 2\,\text{logh}\,\frac{d}{\rho_1} \qquad \frac{\text{abhenrys}}{\text{loop cm.}} \qquad (31)$$

If the linear total inductance of the rail outwards to infinity (L_1) can be measured experimentally for a particular rail length l cm., then the corresponding value to the trolley wire return conductor is

$$L_{10} = L_1 + 2\,\text{logh}\,\frac{d\epsilon}{2l} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (32)$$

The linear loop inductance can thus be determined for any assigned value of the trolley-wire vertical distance d, if the actual linear inductance L_1 of the rail can be correctly measured outwards to infinity for a known rail length of l cm.

If now we consider the practical case of a trolley wire supported over a line midway between two parallel rails (Fig. G), distant b cms. apart on equivalent centres, then it is easily shown that if the mutual inductance between the two rails with respect to the trolley wire return is defined as:

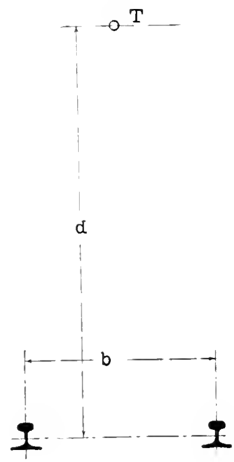
$$M_{12} = 2 \text{ logh } \frac{d}{b} \qquad \frac{\text{abhenrys}}{\text{rail cm.}} \qquad (33)$$

the linear total inductance of the system, formed by the trolley wire with the two rails as joint return conductors, is

$$L = L_{01} + \frac{L_{10}}{2} + \frac{M_{12}}{2} = \frac{\mu_0}{2} + 2 \text{ logh } \frac{d}{\rho_0} + \frac{L_{1i}}{2} + \text{logh } \frac{d}{\rho_1} + \text{logh } \frac{d}{b} \qquad \frac{\text{abhenrys}}{\text{system cm.}} \qquad (34)$$

It may be observed that as the two rails are brought closer together, M_{12} is increased; and, finally, if they be merged together

FIG. G.



Cross-section of track and trolley wire. The distance d should be measured from centre of trolley wire to the centre of either rail.

into a single rail, $M_{12} = L_{10}$, so that the last formula reduces to (31) for the case already found of a trolley wire and one rail. The value of M_{12} can always be computed from (33) with satisfactory practical precision. If, therefore, we measure the linear inductance L_1 of a given length l of the rail for infinite flux radius, we can readily compute the system linear inductance for assigned values of d and b by (33) and (34).

Appendix III indicates the procedure in regard to the geometrical arrangement of the rail circuits for enabling L to be measured. In the presence of skin effect, L_1 becomes reduced to an effective value L_1' abhenrys per rail length l, for infinite flux radius.

APPENDIX III.

THEORY OF CORRECTION FOR MUTUAL INDUCTANCE BETWEEN POTENTIAL LEADS AND RAIL CIRCUIT.

In order to determine the mutual inductance between the rail potential leads and the rectangular loop formed by the rail circuit, it was necessary to solve certain preliminary problems.

First.—A straight wire OO' of any small cross-section lies

FIG. H.

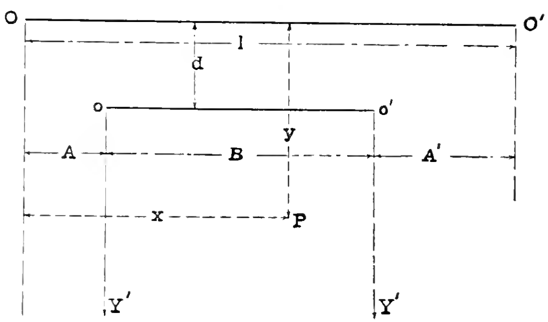


Diagram of geometrical relations between parallel conductors.

parallel to a shorter wire oo', also of small cross-section, the geometrical distances are A, B, A', and d cms. respectively, as shown in Fig. H. Required the mutual inductance between OO' and oo'; *i.e.*, to find the flux emitted by 1 absampère in OO' which enters a rectangle $Yoo'Y'$ containing oo', the sides Y and Y' being indefinitely long. Any point P in the plane of this rectangle has rectangular coördinates x and y.

The field intensity H_P at P due to a current of I absampères in OO' is

$$H_P = \frac{I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\} \quad \frac{\text{* gilberts}}{\text{cm.}} \qquad (35)$$

* E. B. Rosa, *Bulletin,* vol. 4, No. 2, Bureau of Standards, 1907, p. 303, formula (1).

and the corresponding flux density in a medium of permeability μ is:

$$B_P = \frac{\mu I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\} \quad \text{gausses} \qquad (36)$$

The total flux ϕ in the rectangle $Yoo'Y'$ will be

$$\phi = \int_A^{l-A'}\int_d^{\infty} B_P.dy.dx \quad \text{maxwells} \qquad (37)$$

Taking one integration at a time,

$$\frac{d\phi}{dy} = \int_A^{l-A'} B_P.dx = \int_A^{l-A'} \frac{\mu I}{y}\left\{\frac{x}{\sqrt{x^2+y^2}} + \frac{l-x}{\sqrt{(l-x)^2+y^2}}\right\}dx \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (38)$$

$$= \frac{\mu I}{y}\left[\sqrt{x^2+y^2} - \sqrt{(l-x)^2+y^2}\right]_A^{l-A'} \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (39)$$

$$= \frac{\mu I}{y}\left\{\sqrt{(l-A')^2+y^2} - \sqrt{A^2+y^2} - \sqrt{A'^2+y^2} + \sqrt{(l-A)^2+y^2}\right\} \quad \frac{\text{maxwells}}{\text{cm. along } Y} \qquad (40)$$

and

$$\phi = \mu I \int_d^{\infty}\left\{\frac{\sqrt{(l-A')^2+y^2}}{y} + \frac{\sqrt{(l-A)^2+y^2}}{y} - \frac{\sqrt{A'^2+y^2}}{y} - \frac{\sqrt{A^2+y^2}}{y}\right\}dy \quad \text{maxwells} \qquad (41)$$

Observing that

$$\int \frac{\sqrt{c^2+y^2}}{y}\,dy = \sqrt{c^2+y^2} - c\,\text{logh}\,\frac{c+\sqrt{c^2+y^2}}{y} \qquad (42)$$

c being any constant,

$$\phi = \mu I\Bigg[\sqrt{(l-A')^2+y^2} - (l-A')\,\text{logh}\,\frac{(l-A')+\sqrt{(l-A')^2+y^2}}{y}$$

$$+ \sqrt{(l-A)^2+y^2} - (l-A)\,\text{logh}\,\frac{(l-A)+\sqrt{(l-A)^2+y^2}}{y}$$

$$- \sqrt{A'^2+y^2} + A'\,\text{logh}\,\frac{A'+\sqrt{A'^2+y^2}}{y}$$

$$- \sqrt{A^2+y^2} + A\,\text{logh}\,\frac{A+\sqrt{A^2+y^2}}{y}\Bigg]_d^{\infty} \quad \text{maxwells} \qquad (43)$$

All of the terms sum to zero at the upper limit (∞) so that

$$-\phi = \mu I \left\{ \sqrt{(l - A')^2 + d^2} - (l - A') \operatorname{logh} \frac{(l - A') + \sqrt{(l-A')^2 + d^2}}{d} \right.$$
$$+ \sqrt{(l - A)^2 + d^2} - (l - A) \operatorname{logh} \frac{(l - A) + \sqrt{(l - A)^2 + d^2}}{d}$$
$$- \sqrt{A'^2 + d^2} + A' \operatorname{logh} \frac{A' + \sqrt{A'^2 + d^2}}{d}$$
$$\left. - \sqrt{A^2 + d^2} + A \operatorname{logh} \frac{A + \sqrt{A^2 + d^2}}{d} \right\} \quad \text{maxwells} \quad (44)$$

The quantity within the final brackets taken with opposite sign is, therefore, the required mutual inductance M abhenrys in a medium of unit permeability.

If we take $A' = A$ this becomes

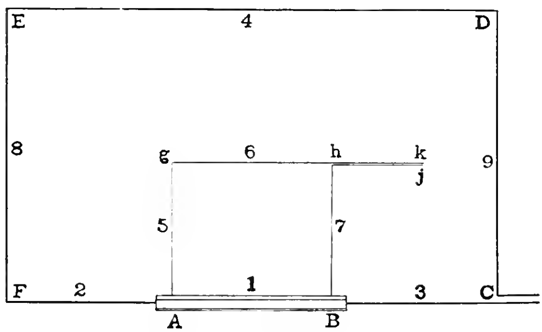
$$-M = 2\left\{ \sqrt{(l - A)^2 + d^2} - (l - A) \operatorname{logh} \frac{(l-A) + \sqrt{(l - A)^2 + d^2}}{d} \right.$$
$$\left. - \sqrt{A^2 + d^2} + A \operatorname{logh} \frac{A + \sqrt{A^2 + d^2}}{d} \right\} \quad \text{abhenrys} \quad (45)$$

If again $A = A' = 0$,

$$-M = 2\left\{ \sqrt{l^2 + d^2} - d - l \operatorname{logh} \frac{l + \sqrt{l^2 + d^2}}{d} \right\} \quad \text{abhenrys} \quad (46)$$

which agrees with formula (98) of Rosa and Grover's "Formulæ for Mutual- and Self-Inductance." *

FIG. K.



System of main and potential circuits in rail tests.

In the system of circuits indicated in Fig. K the working circuit is the rectangle $FABCDE$ and the potential-lead circuit is the inner rectangle nearly in the same plane $ABhgA$. It is required to deter-

* *Bulletin*, vol. 8, No. 1, Bureau of Standards, 1912, p. 151. See also Bibliography 35.

mine by computation the electromotive force induced by each element of the work circuit on the potential circuit, and to find the algebraic sum of the same. The vector subtraction of this sum from the voltage measured at the terminals jk is the vector IZ voltage drop in the rail between the potential points AB.

$$E_{jk} = I\left\{(R_1' + jL_1'\omega) + j\omega\,(M_{1\cdot4} - M_{4\cdot6} + M_{231\cdot6} - 2M_{2\cdot1} - M_{8\cdot5} + M_{8\cdot} + M_{9\cdot5} - M_{9\cdot7})\right\} = I\left\{(R_1' + jL_1'\omega) + j\omega M_0\right\} \quad \text{abvolts}\angle \quad (47)$$

Owing to the symmetry of the rectangles, $M_{8\cdot5} = M_{9\cdot7}$ and $M_{8\cdot7} = M_{9\cdot5}$.

$$\begin{aligned} M_0 &= M_{1\cdot4} - M_{4\cdot6} + M_{231\cdot6} - 2M_{2\cdot1} + 2M_{9\cdot5} - 2M_{8\cdot5} \\ &= 2576 - 3738 + 3697 - 2468 + 256 - 510 \\ &= 6529 - 6716 = -187 \qquad \text{abhenrys} \quad (48) \end{aligned}$$

$$\text{so that } R_1' + j\omega(L_1' - 187) = R_1 + jL_1''\omega = \frac{E_{jk}}{I} \qquad \text{absohms}\angle \quad (49)$$

$$\text{and } L_1' = L_1'' + 187 \qquad \text{abhenrys} \quad (50)$$

In the above computation the term $M_{2\cdot1}$ and its counterpart $M_{3\cdot1}$ are obtained from the end-effect formula (102) of Rosa and Grover in the publication above referred to.

APPENDIX IV.

OUTLINE OF THE THEORY OF SKIN EFFECT IN STEEL RAILS.

The working theory of the extra effective resistance in steel rails due to skin effect, or the imperfect penetration of alternating currents, is based on two provisional assumptions:

1. That the surface of a rail may be regarded as of negligible curvature for the degree of precision required; so that the skin-effect formulas applying to flat strips, as first developed by Lord Rayleigh,* may be utilized. At the curves in the contour of the rail it suffices to assume, as a first approximation, that the magnetic flux densities and electric current densities are distributed in layers of corresponding curvature beneath the surface.

2. That the magnetic permeability μ of the substance of the rail may be taken as substantially constant at any one r. m. s. rail current-strength, in spite of the fact that, at different depths below the surface, the magnetic flux density B dwindles to zero and the

* Bibliography No. 1.

permeability μ is subject to a certain range of variation. This means that we may take a certain average effective value of μ, which may correspond to the more complex integrated value of μ at different depths. Since at the frequency of 25 $\sim$ the flux density must fall to one-half within less than 2 mm. of depth below the surface, the effects of changes in permeability at greater depths than 2 mm. rapidly disappear. This subject has recently been investigated by Lombardi.*

Let $ABCD$ (Fig. L) represent a cross-section of a thick sheet of steel $2X$ cm. in total thickness. Let $abcd$ be a 1-cm. portion

FIG. L.

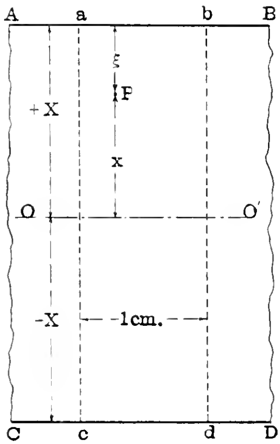


Diagram of cross-section of conducting sheet.

of the section; so that the area of $abcd$ is $2X$ sq. cm. Let the electric current carried in the sheet be directed towards the observer, or be perpendicular to the plane of the paper. Then the magnetic flux in the metal must lie across the current or in the plane of the paper.

At a point P, distant x cm. from the midplane OO' of the sheet, or $\xi = X-x$ cm. below the upper surface AB, let the alternating-current density be i_x r.m.s. absamperes per sq. cm. Then we know†

* Bibliography No. 33.

† Bibliography 32, 36.

that in the case of a very wide sheet this current density varies in simple proportion to the cosine of the hyperbolic angle αx where

$$\alpha = \sqrt{j4\pi\gamma\mu\,\omega} = \sqrt{4\pi\gamma\mu\,\omega}\,/45^\circ = \sqrt{2\pi\gamma\mu\,\omega} + j\sqrt{2\pi\gamma\mu\,\omega} = \alpha_2 + j\alpha_2 \quad cm^{-1} \qquad (51)$$

and $j = \sqrt{-1}$, $\pi = 3.14159\ldots$

γ = conductivity of the sheet (abmhos per cm.)
= $1/\rho$ if ρ is the resistivity of the sheet (absohm–cm.)

μ = permeability of the sheet $\frac{\text{gausses}}{\text{gilberts per cm.}}$

ω = angular velocity of alternating current $\frac{\text{radians}}{\text{second}}$

= $2\pi f$, and f is the impressed frequency $\frac{\text{cycles}}{\text{second}}$

Similarly, the flux density B_x gausses at P varies in simple proportion to the sine of the same hyperbolic angle αx, which as shown by (51) is a semi-imaginary quantity, having equal real and imaginary components, each equal to $\alpha_2 x$.

When the sheet has such thickness that with the proper values of γ, μ, and ω the maximum hyperbolic angle αX has a modulus of, say, 6 or more radians, with therefore components of 4.2 or more, it is known that,* owing to the cosine relations of such large hyperbolic angles,

$$i_x = i_X \epsilon^{-\alpha\xi} = i_X \epsilon^{-\alpha_2\xi} \diagdown \alpha_2\xi \qquad \frac{\text{absampères}}{\text{sq.cm.}} \qquad (52)$$

where i_X is the current density at the surface, and ϵ is the Napierian base, so that the current density falls off as we descend into the sheet according to a simple exponential law, at the same time lagging increasingly in phase.

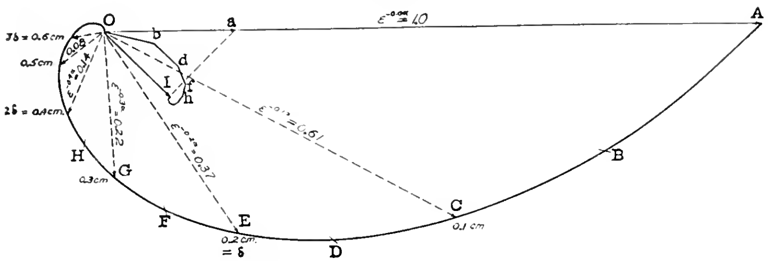
These conditions are indicated graphically in Fig. M. Here the horizontal vector OA, of unit length, represents the alternating-current density at the surface of the strap, in r. m. s. absampères per sq. cm. The diagram is drawn for the particular case where $f = 25\sim$ or $\omega = 157.1$ rad/sec., $\mu = 506.6$, $\rho = 20{,}000$ absohms-cm. or $\gamma = 0.5 \times 10^{-4}$ abmho/cm.; so that $\alpha = 7.071\,/45^\circ = 5 + j\,5$ hyperbolic radians per cm. The current density in layers of successive depth will therefore fall off both in magnitude and in phase at the rate $\epsilon^{-7.071\xi\,/45^\circ} = \epsilon^{-5\xi} \diagdown 5\xi$ radians. If we give to the depth ξ the successive values 0.05, 0.1, 0.15, 0.2 cm., etc., we obtain from this expression the successive vectors OB, OC, OD, OE; and the

* Bibliography 23, 16.

curve *ABCDE* is an equiangular spiral about the origin *O*, the tangent at any point on this curve making an angle of 45° with the radius vector.

It will be observed that at a depth of 3 mm. ($\xi = 0.3$), the current density is 22 per cent. of the density at the surface, and lags nearly 90° with respect thereto. At 6 mm., or 3δ, the current density has fallen to less than 5 per cent., and is nearly in opposite phase to the density at the surface.

FIG. M.



Graph of magnitude and phase of alternating current density at various depths below surface.

The total vector r. m. s. current carried along the sheet per cm. of its breadth may be obtained from the integral

$$I = \int_0^X i \,.\, d\xi = i_X \int_0^X \varepsilon^{-a\xi} \cdot d\xi = \frac{i_X}{\alpha}\left(1 - \varepsilon^{-aX}\right) \qquad \frac{\text{absampères}}{\text{cm. breadth}} \angle \qquad (53)$$

When, as in the condition assumed, aX exceeds 6, ε^{-aX} is numerically less than 0.015; so that we may take the integral current in the half of the strap above the midplane *OO′*, Fig. L, as

$$I = \frac{i_X}{\alpha} = \frac{i_X}{7.071} \diagdown 45^\circ = i_X\,(0.1 - j0.1) \qquad \frac{\text{absampères}}{\text{cm. breadth}} \angle \qquad (54)$$

We may also obtain a close geometrical approximation to the total integral current by taking the vector *OB*, the density at the middle of the first 0.1 cm. layer ($\xi = 0.05$). Multiplying this by 0.1, we find the vector current *Ob* in this layer. Next taking the vector *OD* at the middle of the second 0.1 cm. layer ($\xi = 0.15$), and multiplying it by 0.1, we obtain a vector increment *bd*, to be added vectorially to *Ob*, in order to obtain the total vector current in the first two such layers. Proceeding in this way, the total vector r. m. s. current per cm. of breadth of the sheet above the

midplane OO', Fig. L, will be $OI = i_X 0.1414 \diagdown 45°$ or $i_X\ (0.1 - j\ 0.1)$ absampères per cm. It is evident that if, as in the case assumed, the current has room to penetrate (aX not less than 6.0, say), the total vector current carried by the sheet will lag just 45° behind the superficially impressed electromotive force and the current at the surface.

If we denote by η_X the electric intensity impressed on the sheet in abvolts per linear cm. acting at the surface, and independent of that consumed in overcoming the external reactance, or producing magnetic flux in the external air, then in each cm. of breadth of the strap we have

$$I = \frac{\eta_X}{Z'} \qquad \frac{\text{absampères}}{\text{breadth cm.}} \angle \qquad (55)$$

and at the surface the current density is

$$i_X = \frac{\eta_X}{\rho} = \eta_X \gamma \qquad \frac{\text{absampères}}{\text{sq. cm.}} \angle \qquad (56)$$

The linear impedance of the strap per cm. of breadth and above the midplane OO' is

$$Z' = \alpha\rho = \alpha_2\rho + j\alpha_2\rho \qquad \frac{\text{absohms}}{\text{breadth cm.}} \angle \qquad (57)$$

The alternating-current resistance R' in the presence of skin effect is then

$$R' = \alpha_2\rho \qquad \frac{\text{absohms}}{\text{breadth cm.}} \qquad (58)$$

But the continuous-current resistance R of the strap per cm. breadth and above the midplane OO' is

$$R = \frac{\rho}{X}. \qquad \frac{\text{absohms}}{\text{breadth cm.}} \qquad (59)$$

The resistance R' would be offered to continuous currents by a certain depth δ cm., such that

$$\frac{\delta}{X} = \frac{R}{R'} = \frac{1}{\alpha_2 X} \qquad \text{numeric} \qquad (60)$$

or

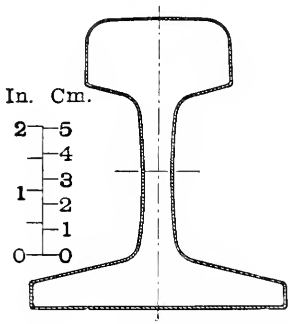
$$\delta = X \cdot \frac{R}{R'} = \frac{X}{\left(\frac{R'}{R}\right)} = \frac{1}{\alpha_2} \qquad \text{cm.} \qquad (61)$$

This equivalent skin depth δ, first arrived at by Rayleigh,* which

* Bibliography 1.

would have the same resistance to continuous currents that the strap above the midplane, offers to alternating currents, is thus equal to the half thickness X divided by the skin-effect resistance-ratio R'/R, and is the reciprocal of a_2. In the case presented in Fig. M, where $a_2 = 5$, the value of δ is $1/5 = 0.2$ cm.; that is, 2-mm. skin, on either surface of the plate, would offer the same continuous current resistance. Referring to Fig. M, if we multiply the surface current density OA by $\delta = 0.2$, we obtain a vector current Oa, which leads the total current OI by $45°$. The projection of Oa on the vector direction of this total current coincides with OI. A skin depth δ, carrying the r. m. s. current density at the surface, would therefore give a total current, the component of which, in

FIG. N.



Rail No. 174

The shaded superficial layer indicates the effective equivalent skin of depth, $\delta = 0.15$ cm.—as deduced from measurements—at 25.5 $\sim$ and maximum permeability.

phase with the total sheet current, is equal in magnitude to the latter, assuming plenty of available depth and $aX = 6$ or more. In such cases, the current density at depth δ, attenuates to $1/\epsilon$th and lags 1 radian behind the surface density.

Fig. N represents the cross-section of an ordinary type of steel rail, the effective skin depth δ being 0.15 cm. The actual value of δ in this rail at 25.5 $\sim$ was found to be 1.55 mm. at μ_{max}. The web of this rail, having a thickness of about 9δ, is fairly well utilized; but the head and the base are only partially utilized for conductance at 25 $\sim$. The linear resistance of this rail with continuous currents, at, say, $20°$ C., is supposed to have been ascertained as R absohms per linear cm. The impedance of the rail at the same temperature to currents of a given impressed fre-

quency will depend on the effective permeability μ, which, in turn, depends upon the average magnetic intensity H_X at the surface,

$$H_X = \frac{4\pi I}{P} \qquad \text{r. m. s. gilberts per cm.} \quad (62)$$

where P is the perimeter of the rail section in cm. At any assigned number of r. m. s. ampères in the rail, the average value of H_X will be this number multiplied by $\frac{1.257}{P}$. The linear resistance of the rail at this current strength will be, say, R' absohms per cm. With continuous currents, the whole area of cross-section S sq. cm. will be effective for carrying current, but with the alternating current the effective area S' will be reduced in the ratio $\frac{R}{R'}$, so that,

$$S' = S\frac{R}{R'} \qquad \text{sq. cm.} \quad (63)$$

This effective area S' of alternating-current-carrying capacity is nearly equal to the effective skin depth δ multiplied by the rail perimeter P, or

$$\delta = \frac{S'}{P} = \frac{S}{P}\cdot\frac{R}{R'} = \frac{1}{\alpha_2} \qquad \text{cm.} \quad (64)$$

Consequently

$$\frac{R'}{R} = \frac{S}{P}\cdot\alpha_2 = \frac{S}{P}\sqrt{2\pi\gamma\mu\,\omega} = \frac{S}{P}\,2\pi\sqrt{\gamma\mu f} \qquad \text{numeric.} \quad (65)$$

Since $R = \rho/S = 1/S\gamma$, it follows that

$$R' = \frac{2\pi}{P}\sqrt{\frac{\mu f}{\gamma}} \qquad \frac{\text{absohms}}{\text{cm.}} \quad (66)$$

or calling $G' = 1/R'$ the linear conductance in the presence of skin effect,

$$G' = \frac{P}{2\pi}\sqrt{\frac{\gamma}{\mu f}} \qquad \text{abmho-cm.} \quad (67)$$

Similarly, if G is the linear conductance of the rail to continuous currents, or in the absence of skin effect; then the skin-effect conductance ratio, or the fraction of utilization of the rail section, is by (64),

$$\frac{G'}{G} = \frac{P}{2\pi S\sqrt{\gamma\mu f}} = \frac{P}{S\sqrt{2\pi\gamma\mu\omega}} = \frac{P}{S\alpha_2} \qquad \text{numeric} \quad (68)$$

If, therefore, we can find γ and μ for the quality of steel employed in the rail, taking into account the temperature and the value of H_X for the current I, we can compute the skin-effect resistance ratio $\frac{R'}{R}$ at that current. Thus, with $\alpha_2 = 5$, $S = 65$ sq. cm., and

$P = 60$ cm., $\frac{R'}{R} = 5 \times 1.083 = 5.42$. A curve of $\frac{R'}{R}$ may then be plotted for different alternating current strengths carried by the rail, based on the known curve connecting μ and H.

Errors in the Method.

There are two very noticeable sources of error in the above computation; namely, (1) permeability error, (2) shape error.

Permeability Error.—If the permeability μ in formula (65) is taken at the value observed with continuous-current permeameter measurements on a sample bar, for the value of H at the rail surface, corresponding to a given current strength through the rail by (62), it cannot be expected to lead to a correct result for the skin-effect resistance ratio R'/R, since the value of alternating H dwindles at the increasing depths below the rail surface, and the permeability will correspondingly vary. The direction and extent of this error will depend upon the shape of the $\mu - H$ curve for the steel, upon the rate of dwindling as we descend below the surface, and as to whether the maximum value of the permeability is exceeded at the value of H reached on the surface. Since, however, in ordinary steels, the equivalent skin depth δ at electric-railroad frequencies seldom exceeds 2 mm. and the conductance in this skin depth usually greatly preponderates over the sum of all the conductances at depths underlying δ, the errors attributable to this variation in μ at different depths appears by actual measurement to be relatively small, especially in the neighborhood of maximum permeability at the surface.

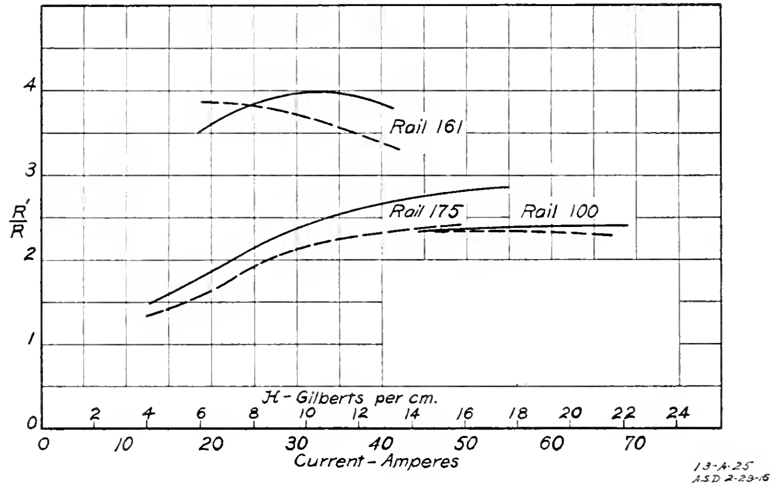
The use of the permeameter value of μ in (65) is also in error, because the ordinary permeameter measures the permeability of the steel sample bar longitudinally, or in the direction of its axis; whereas alternating currents in the rail set up magnetic fluxes near the surface directed cylindrically, and in planes transverse to the axis. Strictly speaking, the transverse permeability and not the longitudinal permeability should be used. It has been found by Miller * that in the case of steel wires and rods there were in some cases appreciable differences between the longitudinal and transverse permeabilities. However, the error attributable to the differences reported seems to be small by comparison with the outstanding errors. It should be noted that the resistance ratio

* Bibliography No. 34 (Bureau of Standards).

R'/R depends on the square root of the permeability, and an error of, say, 5 per cent. in μ would involve only about 2 per cent. in R'/R.

Another source of error in formula (65) is due to the fact that with alternating magnetic fluxes in the skin of the rail there will assuredly be power lost in magnetic hysteresis * and this will tend to increase the apparent resistance of the rail considered as a simple steel cylinder. For this reason, the R'/R found by alter-

FIG. P.



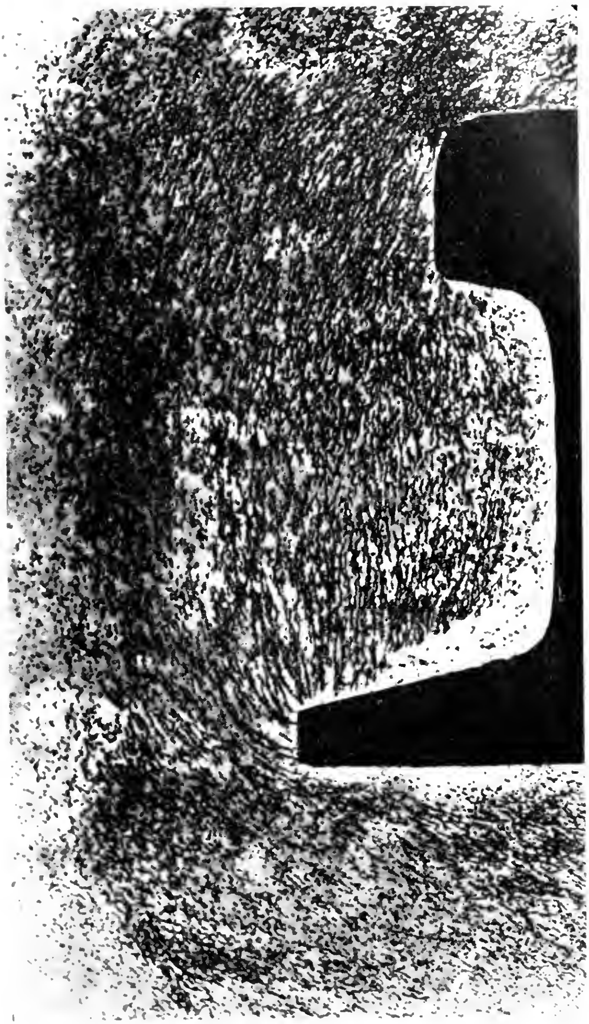
Skin effect at 60 ∿ of steel rods cut from rails. Solid curves observed. Dotted curves calculated.

nating-current measurement in a bar of steel tends to be greater than that computed from the frequency resistivity and permeability by (65), even when the correct value of μ is assumed.

Fig. P compares the resistance ratio R'/R of steel cylinders (38 cm. long and 1.25 cm. in diameter) as measured, and as deduced from the longitudinal resistivity and permeability of the same material. The ordinates are R'/R, and the abscissas are H_X in gilberts/cm. In the case of the steel cylinder cut from rail No. 175, the observed resistance ratio exceeded throughout the value computed by formula (65). In the case of the cylinder cut from rail No. 100, the agreement was very close; while in the cylinder cut from rail No. 161, the curves cross at $H_X = 8$. It appears

* Lombardi, Bibliography, No. 33.

FIG. Q.



Iron-filing diagram of alternating-current magnetic flux surrounding an active rail.

from these results that the resistance-ratio of cylinders cut from these steel rails agrees fairly well with that deduced from the longitudinal resistivity and permeability of the same rod at the same temperature.

Shape Error.—Since the ordinary steel rail is everywhere so thick by comparison with the equivalent skin-depth δ at 25 ∾ that the current density has ample room for attenuation according to (52), the only important error to be considered is the departure from the simple cylindrical form. If the rail were externally cylindrical, the magnetic flux at the surface would be conformal to it at every point. In the actual I or T shape, the magnetic flux tends to pass through the surrounding air from one projection to another, as is shown in Fig. Q, where an iron-filings picture was obtained on one side of a rail (No. 161), when an alternating current of 275 ampères r. m. s. at 60∾ was passing along the rail. It will be seen that the magnetic flux cuts across corners, as though from polar projections, and in passing through the surface of the rail generates alternating electromotive forces in the skin. These electromotive forces, if allowed to close their circuits locally, would produce local eddy currents and consume power, tending to increase the apparent linear resistance R' of the rail. Since, however, the electromotive forces are generated symmetrically throughout the entire length of the rail, we may expect that they will markedly increase the current density at the edges of projections in the contour, and so increase the apparent resistance. This is the same effect as was observed in the case of a steel strap, 3.8 cm. wide and 0.64 cm. thick. The skin-effect resistance ratio R'/R for this strap was found to be 46 per cent. greater than was deducible from its longitudinal resistivity and permeability. It may be called the " edge effect," and is essentially the same phenomenon as occurs in a cylinder; *i.e.*, the current leaves the central region, and crowds into the most distant regions of the cross-section.

The magnitude of the edge-effect coefficient in a steel rail is too complex to be attempted by calculation at the present time. It can, however, be determined experimentally for a given rail section and material, provided we assume that the R'/R of the same rail perimeter, in the form of a cylinder, would be the same as that computed from the longitudinal permeability and resistivity by (65). In other words, if we ignore the permeability and hysteresis errors as trivial by comparison with the shape error and edge effect, the observed value of R'/R for a rail, when divided by the computed value of R'/R, gives the edge-effect coefficient.

LIST OF SYMBOLS EMPLOYED.

α_{20}	Temperature coefficient of resistivity for rail; referred to 20° C. (Temperature $^{-1}$.)
$\alpha = \sqrt{4\pi\gamma\mu\,\omega}\ /45^\circ$	Propagation constant for a flat strip, a positive semi-imaginary (cm. $^{-1}\angle$).
$\alpha_2 = \sqrt{2\pi\gamma\mu\,\omega}$	Imaginary or real component of a semi-imaginary propagation constant (cm. $^{-1}$).
B	Flux density (gausses $\angle$).
B_s	Flux density in air gap of Sumpner dynamometer due to potential drop in S (gausses $\angle$).
B_P	Flux density at point P of infinite sheet (gausses $\angle$).
B_x	Flux density at distance x from midplane of sheet (gausses $\angle$).
b	Distance between centres of rails (cm.).
$\gamma = 1/\rho$	Electric conductivity of material (abmhos per cm.).
C_1	Condenser in series with moving coil of Sumpner dynamometer.
C_S	Capacitance of condenser C_1 when M is connected across the shunt S (farads).
C_R	Capacitance of condenser C_1 when M is connected across the rail (farads).
δ	Thickness of equivalent skin (cm.).
D_S	Deflection of dynamometer when M is connected across the shunt S (cm.).
D_R	Deflection of dynamometer when M is connected across the rail (cm.).
D_X	Deflection of dynamometer when M is connected across the rail and R_M substituted for C_1 (cm.).
d	Vertical distance between equivalent centre of rail and the trolley wire (cm.).
E_{AB}	Drop of potential in rail (volts $\angle$).
E_{jk}	Voltage as measured at potential leads jk (volts $\angle$).
E_s	Drop of potential in shunt S (volts).
$\epsilon = 2.71828\ldots$, Napierian base.	
η	r. m. s. electric intensity impressed on sheet and acting at surface (abvolts per linear cm. $\angle$).
f	Frequency (cycles per second).
G	Linear conductance of a rail in the absence of skin effect (abmhos/cm.).
G'	Linear conductance of a rail in the presence of skin effect (abmhos/cm.).
H	R. m. s. values of magnetic intensity (gilberts per cm. $\angle$).
H_P	R. m. s. values of magnetic intensity at point P (gilberts per cm. $\angle$).
H_X	Average r. m. s. magnetic intensity at surface of sheet (gilberts per cm. $\angle$).
I	R. m. s. current in rail (ampères $\angle$); strap absamp/cm.

I_{MS}	R. m. s. current in moving coil of dynamometer and condenser C, due to potential drop in shunt S (ampères $\angle$).
I_{MC}	R. m. s. current in moving coil of dynamometer and condenser C, due to potential drop in rail (ampères $\angle$).
I_{MX}	R. m. s. current in moving coil of dynamometer and resistance R_M, due to potential drop in rail (ampères $\angle$).
i_x	R. m. s. current density at ξ cm. from surface of sheet (absampères per sq. cm. $\angle$).
i_X	R. m. s. current density at surface of sheet (absampères per sq. cm. $\angle$).
$j = \sqrt{-1}$.	
L'	Total inductance of rail in presence of skin effect (henrys).
L_{oe}	External linear inductance of wire to infinity (abhenrys per cm.).
L_{oi}	Internal linear inductance of wire (abhenrys per cm.).
L_o	Total linear inductance, outwards to infinity, of trolley wire (abhenrys per cm.).
L_{1i}	Internal linear inductance of rail (abhenrys per cm.).
L_{1e}	External linear inductance of rail, outwards to infinity (abhenrys per cm.).
L_1	Total linear inductance of rail, outwards to infinity (abhenrys per cm.).
L_{10}	Total linear inductance of rail in presence of trolley return wire (abhenrys per cm.).
L	Total linear inductance of loop of trolley and rail (abhenrys per loop cm.).
L'_1	Total inductance of rail in presence of trolley wire and skin effect (abhenrys).
L''_1	Apparent total inductance of rail as measured by dynamometer (abhenrys).
l	Length of trolley wire (cm.).
$logh$	Napierian or hyperbolic logarithm.
M	Moving coil of Sumpner dynamometer.
M_{01}	Mutual linear inductance of trolley and rail (abhenrys per cm.).
M_{12}	Mutual linear inductance of two rails with respect to trolley wire (abhenrys per cm.).
μ	Permeability of rail as measured by direct-current methods $\dfrac{\text{gausses}}{(\text{gilberts per cm.})}$.
μ_0	Permeability of trolley wire $\dfrac{\text{gausses}}{\text{gilberts per cm.}}$.
V_{60}, V_{25}	Values of resistance ratio R^1/R, at 60 $\backsim$ and at 25 $\backsim$ respectively (numeric).
ξ	Distance of point P below surface of sheet (cm.).
P	Perimeter of rail (cm.).
$\pi = 3.14159\ldots$	
R'_T	Effective resistance of rail at T° C. (ohms).

R'_{20}	Effective resistance of rail at 20° C. (ohms).
R'	Effective a. c. resistance of rail as measured (ohms). Also its effective linear a. c. resistance (absohms cm.).
R	Direct-current resistance of rail (ohms). Also its linear resistance (absohms / cm.).
R'/R	Skin-effect resistance ratio.
R_M	Resistance substituted for C_1 in moving-coil circuit of dynamometer.
ρ	Resistivity of sheet or rail (absohms-cm.).
ρ_1	Equivalent radius of rail (cm.).
ρ_o	Radius of trolley wire (cm.).
r. m. s.	Root-mean-square value.
S	Area of rail (sq. cm.).
S'	Effective equivalent area of rail to alternating currents (sq. cm.).
S	Resistance of shunt in rail testing circuit (ohms).
T	Value of temperature (degrees Cent.).
τ_s	Torque due to potential drop in S (dyne perp. cm.).
τ_X	Torque due to potential drop in rail with R_M in circuit (dyne perp. cm.).
τ_R	Torque due to potential drop in rail with C_1 in circuit (dyne perp. cm.).
X	Half-thickness of sheet (cm.).
$\omega = 2\pi f$	Angular velocity of impressed alternating current (radians per second).
Z'	Impedance of sheet per cm. of breadth and above the mid-plane (absohms per breadth cm.).
ab or *abs*	Prefix denoting a C. G. S. magnetic unit.
$\angle$	Indication of a complex or plane-vector unit.

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Hydrogen for Military Purposes. E. D. ARDERY. (*Proceedings of the American Electrochemical Society*, April 27–29, 1916.)—For military purposes, hydrogen finds its most important use in inflating balloons, either captive or free. The ascensional force of any gas equals the weight of air minus the weight of an equal volume of the gas, and depends upon the specific gravity, temperature, and barometric pressure of the atmosphere. Hydrogen has twice the ascensional force of pure coal gas and is universally used for military balloons. It permits the employment of smaller balloons, which facilitates transportation and rapid filling, besides affording the enemy a smaller target.

Probably the first method used in generating the gas consisted in the employment of iron or zinc filings and sulphuric acid. The gas from zinc and sulphuric acid is purer than when iron is used. One hundred pounds of sulphuric acid and about 140 pounds of zinc yield 1000 cubic feet of hydrogen. A balloon with a capacity of 16,000 cubic feet would thus require about two tons of these materials, and it is evident that the problem of handling material in the field, to say nothing of the generating and other necessary apparatus, is a serious one. Many processes have been devised to meet the exacting requirements of campaign operations. Among these may be mentioned the "Hydrogenit" process. This is particularly adapted for use where an abundance of water is not available. Hydrogenit is a mixture of finely powdered ferro-silicon and sodium-calcium oxide. It is a gray, sandy substance which, even in a closed receptacle, burns with a large production of hydrogen. The mixture is ignited by means of a match or a small amount of ignition powder. It comes in sheet-metal containers, and is said to keep indefinitely at normal temperatures. The containers are placed bodily in a water-jacketed producer and fired. Calcium hydride is another substance, known as "Hydrolith," which evolves hydrogen rapidly when dropped into water. The objection to it is its excessive cost. Some of the alleged costs per cubic metre (35 cubic feet) of hydrogen gas, according to the process used, are: Ferro-silicon, 20 cents; hydrogenit, 32 cents; hydrolith, 100 cents; steam and hot iron filings, 3 cents; distillation of crude oil and tar, 3½ cents; water gas, 25 cents; old method of iron and sulphuric acid, 25 cents; calcium hydride, 175 cents; silicon and caustic soda, 210 cents. By electrolysis, 1500 ampères produce 23 cubic feet (0.66 cubic metre) of hydrogen and 11½ cubic feet (0.33 cubic metre) of oxygen per cell per hour.

To follow an army's movements, portable plants are necessary, but it appears to be the practice, when possible, to generate the gas in the more economical stationary plants and distribute the product highly compressed in steel cylinders. The compressed gas has the considerable advantage of being immediately available for use. The objections to it are the danger of explosion and the dead weight to be carried.

ON SOME PROPOSED ELECTRICAL METHODS OF RECORDING GAS FLOW IN CHANNELS AND PIPES BASED ON THE LINEAR HOT-WIRE ANEMOMETER.*

BY

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Section 1. *The Venturi Meter in the Measurement of Gas Flow.*

The application of the hot-wire method of measuring gas flow proposed by the writer [1] depends primarily on its use in conjunction with a Venturi meter as a standard of reference. The reliability of this meter now seems to be well established from the experiments of Coleman,[2] Thomas,[3] and others: according to these writers, however, no method has as yet been devised for obtaining a graphic record by this means. In addition, the measurement of mass-flow by the Venturi meter requires simultaneous record of density.

In order to obtain a sufficiently great pressure-difference (usually amounting to a few inches of water) to be read accurately on the type of pressure-gauges heretofore employed in engineering practice, it has been customary to make use of a somewhat high degree of constriction in the Venturi tube (ratio of radii generally about ½). In these circumstances it is usual to employ, in the calculation of flow, the somewhat complicated adiabatic formula (due to Saint-Venant):

$$Q = A_2(p_2/p_1)^{1/\gamma}.[2p_1\rho_1/(\gamma - 1)]^{\frac{1}{2}} \frac{[1 - (p_2/p_1)^{(\gamma-1)/\gamma}]^{\frac{1}{2}}}{[1 - (A_2/A_1)^2(p_2/p_1)^{2/\gamma}]^{\frac{1}{2}}} \quad . \quad . \quad (1)$$

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* Communicated by the Author.

[1] King, L. V., "Precision Measurement of Air Velocity by Means of the Linear Hot-Wire Anemometer," *Phil. Mag.*, **29**, April, 1915, pp. 556–577. Journ. Franklin Inst., vol. 18, 1916.

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where Q is the flow in grammes per sec., A_1 and A_2 the cross-sectional areas at the upstream section and constriction of the Venturi tube respectively, expressed in cm.^{2}: p_1 and p_2 are the corresponding absolute pressures measured in dynes per cm.^{2} and ρ_1 is the density of the gas at the upstream section expressed in grammes per cm.^{3}, while γ is the ratio of specific heats ($\gamma = 1.40$ for air).

In the case of producer-gas[4] which contains small particles of tar-fog in suspension, tar deposits are liable to occur at the constriction, resulting in a decrease of accuracy in flow measurement.

In the application of this method to be used in conjunction with a recording linear hot-wire anemometer, it is proposed to employ an extremely sensitive Töpler differential manometer[5] for measuring pressure-differences across a Venturi tube of much less constriction than is usually employed. This manometer is easily capable of measuring 1 dyne per cm.^{2} (about 10^{-6} atmospheres), so that the Venturi meter may be designed to give pressure-difference of about 5 mm. water (490 dynes per cm.^{2}) at the maximum flow if readings are desired to an accuracy of about ½ per cent. Among the advantages of this method may be mentioned the following:

1. Owing to the small degree of constriction it is easily verified that the complicated Saint-Venant formula (1) from which the flow is calculated is indistinguishable to an accuracy of one part in a thousand from that calculated from the simple formula for incompressible fluids

$$Q = A_1 \sqrt{[2(p_1 - p_2)\rho]/[(A_1/A_2)^2 - 1]}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Q being as before the mass-flow in grammes per second, A_1 the

[4] A type of meter suitable for measuring the flow of producer gas is mentioned by B. F. Haanel and J. Blizard in a report on tests of lignite samples (Summary Report of the Mines Branch of the Department of Mines, Ottawa, 1914, p. 118).

[5] For the original description of this instrument, see a paper by A. Töpler, *Ann. d. Phys.*, **56**, p. 610, 1895: also Müller-Pouillet, "Lehrbuch der Physik," vol. i, p. 462. This instrument has been found extremely satisfactory by the writer in the course of experiments on the flow of air in channels. The principal dimensions of the instrument illustrated in Fig. 3 are: distance between centre lines of hinge and micrometer-screw, 45.1 cm.; length of xylol thread, about 23 cm.; micrometer-screw, ½ mm. thread-divided head gives 100 divisions, capable of subdivision by vernier into tenths.

cross-section in cm.^{2} of the upstream section, A_2 that of the constriction, $(p_1 - p_2)$ the pressure difference measured in dynes/cm.^{2}, and ρ the mean density of the gas in grammes/cm.^{3}

2. Tar-fog is less liable to deposit in a Venturi meter in which the degree of constriction is small; in any case, any such tendency can probably be eliminated by maintaining the walls of the Venturi tube at a temperature of a few degrees above that of the gas flowing through it. It is well known that a surface under these conditions tends to repel small particles held in suspension in the gas.[6]

3. Difficulties due to pulsations in the gas line are probably lessened owing to the diminished "choking effect" at the constriction. Oscillations in the Töpler manometer due to this cause can easily be damped out and average pressures read.

Numerical Example.—Consider a 6-inch main conveying producer-gas at about atmospheric pressure at a rate varying between 4000 cubic feet and 15,000 cubic feet per hour. This corresponds to a flow from 1.11 to 4.16 cubic feet per second and a mean velocity between 5.7 and 21.2 feet per second. A diameter of 4.5 inches at the constriction is easily verified to give a pressure-difference of 5 mm. water at the maximum flow, thus:

$$A_1 = 0.196 \text{ sq. ft.} = 182.0 \text{ cm.}^2 \quad A_1/A_2 = [6/(4.5)]^2$$

Assuming the density of the producer-gas to be 1.07 grammes per litre, formula (1) gives $Q = 5.71\sqrt{(p_1 - p_2)}$, and hence when

$p_1 - p_2 = 5$ mm. water $= 490$ dynes/cm.^{2}, $Q = 126.1$ grammes/sec. $= 15{,}000$ cu. ft. per hr.
" $= 0.36$ mm. " $= 35$ " $Q = 33.8$ " $= 4{,}000$ "

Section 2. *Electrical Recording Meter for Low Velocities.*

When the velocity in a pipe does not exceed 90 feet per second, the simplest method of adapting the writer's system of hot-wire anemometry to the recording of gas flow is to insert an anemometer-wire in the line on the upstream side of the Venturi tube section as shown in Fig. 1*a*. According to the principles developed in the writer's work already mentioned,[7] the wire is to be kept

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[6] On this subject see Rayleigh, *Roy. Soc. Proc.*, **34**, pp. 414–418, 1882; "Collected Works," vol. ii, p. 151. A discussion, together with further references, is given in *Nature*, **94**, Feb. 4, 1915, p. 615.

[7] See reference (1), p. 571 and also p. 574.

FIG. 1 *a*.

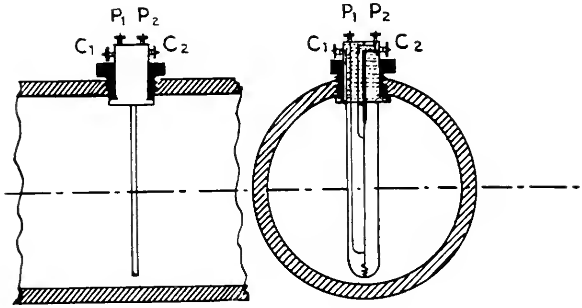
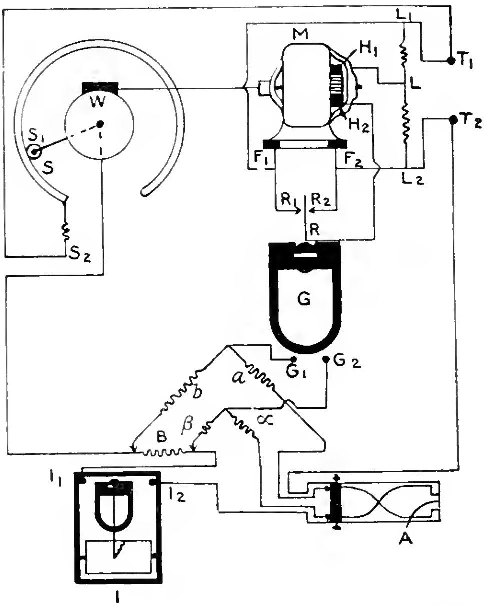
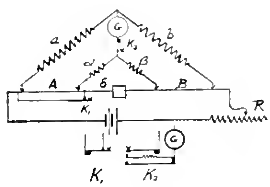


FIG. 1 *b*.





Measurement of Gas Flow in Pipes and Channels by Means of the Recording Linear Hot-wire Anemometer.

Fig. 1 *a* shows an application of the linear hot-wire anemometer adapted to the measurement of flow of gases through large pipes (diameter greater than 3 inches). A brass screw-plug, threaded so as to be capable of insertion in a threaded hole cut into the pipe, carries a central portion of insulating material as shown in the diagram. Fastened to this insulating portion is a stiff framework of narrow, thin steel strip bent in the form of a U, serving both to protect the wire from injury as well as to carry the current to the anemometer-wire from one of the terminals C_1. The other current-terminal C_2 and the potential terminals P_1 and P_2 are disposed as shown in the diagram.

In order to make the readings of flow as given by the recording apparatus Fig. 1 *b** independent of temperature fluctuations in the gas, it is only necessary to construct the ratio-coils α and a of the Kelvin double bridge of a wire or a combination of wires having the same temperature as the anemometer-wire, and arrange to have these coils exposed to the gas whose flow it is desired to measure.† This may easily be accomplished by inserting in the pipe-line the coils referred to, wound on a framework attached to a screw-plug similar to that already described.

In the larger sizes of pipes a flow-equalizer, consisting of a grid similar to that employed

for the same purpose in the wind-tunnels of aërotechnical laboratories, would probably improve the accuracy and consistency of flow measurement by this means.‡

The type of flow meter just described would have to be calibrated by a comparison with the readings of an absolute meter of the Venturi type. Hence in most applications it would appear preferable to employ the combination of the Venturi meter and the linear hot-wire anemometer as described under Fig. 2.

* For a description of this design of a recording apparatus and its mode of operation see British Patent Specification No. 18,563, 1914, or the writer's paper, "The Linear Hot-Wire Anemometer and its Applications in Technical Physics," JOURNAL OF THE FRANKLIN INSTITUTE, January, 1916.

† On the theory of this mode of temperature compensation see the writer's paper, "Precision Measurement of Air Velocity by Means of the Linear Hot-Wire Anemometer," *Phil. Mag.*, 29 April, 1915, pp. 571–572.

‡ The writer is indebted to Dr. R. B. Owens for this suggestion.

automatically at a fixed average temperature of 50° C. to 100° C. above that of the surrounding gas, and the current required to maintain this temperature charted on a recording ammeter. The record must, of course, be calibrated from time to time in terms of the direct Venturi meter and Töpler manometer readings.

According to the theory of the convection of heat from small cylinders developed by the writer,[8] it will be noticed that the energy dissipated as heat from a wire maintained at constant average temperature (and therefore resistance) depends on the product (density × velocity) and on the specific heat, thermal conductivity, and, to a small extent, viscosity of the gas. The specific heat (per unit mass) is known to be independent of pressure and temperature for a gas of constant composition, while the thermal conductivity and viscosity are independent of the pressure and only vary comparatively slowly with temperature over such a range as would probably be met in practice.

Some of the advantages of this method of registration are as follows:

1. The graphical ammeter record obtained in this way can be interpreted as a continuous record of mass-flow or flow in cubic feet per second, measured at standard temperature and pressure. Values of flow so obtained are practically independent of pressure fluctuations in the mains. Any small effect due to temperature fluctuation can easily be compensated for by a suitable design of ratio coils.

2. By integrating this record the total flow during any period can be obtained.

3. The electrical recording apparatus can be installed at any distance from the main, and by a simple commutating device

[8] King, L. V., "On the Convection of Heat from Small Cylinders, etc.," *Phil. Trans. Roy. Soc. Lond.*, vol. 214A, p. 381.

records of flow in several mains may be registered on the same chart.

The difficulties anticipated in the application of this method of measurement to tar-fogged gas such as producer-gas are as follows:

1. Difficulties arising from the varying composition of the gas are inherent in all existing methods of measuring gas-flow. Thomas[9] found, however, from experiments carried out during the development of his electric meter, that the specific heat of illuminating gas remained remarkably constant throughout wide variations in composition. As the interpretation of the records of gas flow by the method just indicated are ultimately controlled by the absolute readings of the Venturi meter, this source of difficulty is easily allowed for if it should be found to exist at all.

2. Tar deposits on the anemometer-wire: as has already been mentioned in Section 1, a heated wire tends to repel small particles suspended in a gas, so that no difficulty is anticipated from this cause. This point is confirmed by the experiments of Thomas in connection with the development of his electric meter.[10] The anemometer-wire is to be maintained at as high a temperature as is consistent with no decomposition of the gaseous constituents.

3. Inspection of the anemometer-wire might necessitate closing down the line: in order to overcome this difficulty it might be necessary to install anemometer-wires in duplicate.

Section 3. *Recording Venturi Meter for High Velocities.*

When the velocities in a pipe greatly exceed 90 feet per second the direct measurement of flow by the hot-wire method is unsuitable, as variations of temperature and resistance become small with increasing velocities. In such cases two small pipes are connected to the upstream and constricted portions of the Venturi tube, and between them is inserted a narrow channel of rectangular cross-section whose dimensions are so adjusted that the pressure-differences due to the range of flow through the Venturi meter will give rise to gas velocities in this "shunt channel" of amounts most suitable for graphical recording by a fine anemometer-wire

[9] Thomas, C. C., "Some Recent Developments in Gas Measuring Apparatus," *Proc. Am. Gas Inst.*, Oct., 1912, pp. 41–42

[10] Thomas, C. C., "The Measurement of Gases," JOURN. FRANKLIN INST., Nov., 1911, pp. 446 and 458. See also reference 9, p. 22.

mounted in the centre of this channel. The main features of this arrangement are shown in Fig. 2 and are there described in further detail.[11] The recording linear hot-wire anemometer thus becomes a device enabling the Venturi meter to be made self-recording. The record thus obtained has the property already mentioned of measuring mass-flow independently of pressure-fluctuations, while any effect due to temperature changes, if existent, can easily be compensated. The records must, of course, be calibrated in terms of the pressure readings of the Töpler gauge placed across the Venturi meter.

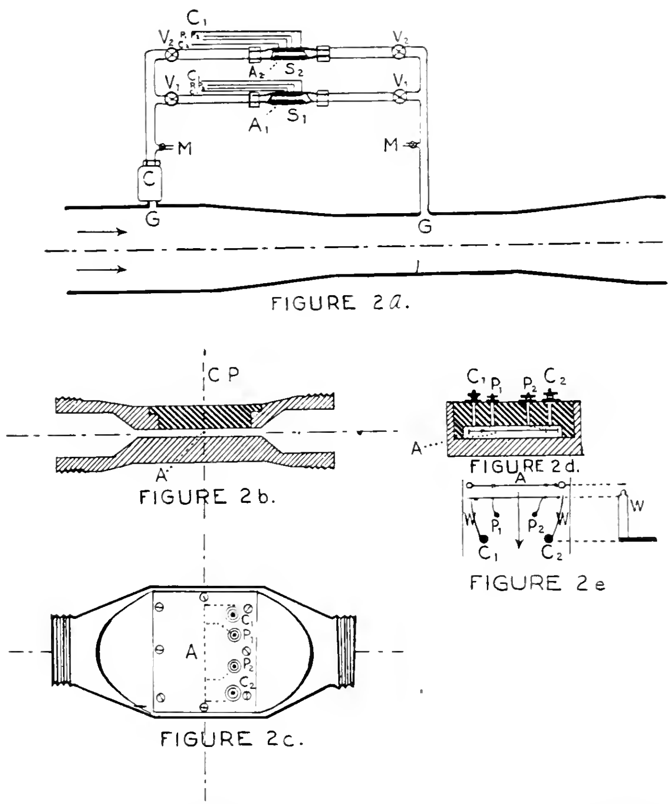
This method seems directly applicable to the measurement of compressed-air distribution, flow of *dry* steam, *dust-free* gas at high pressures, etc., under conditions of wide fluctuations of pressure where existing methods of metering are difficult of application. The advantages of electrically recording gas flow already enumerated in the preceding section apply in this case also. More particularly, the connections just described lend themselves more easily to the installation of duplicate " shunt channels " and offer greater facilities for repairs and inspection without interrupting the flow or the recording.

In addition to the difficulties already mentioned in the preceding section with reference to the measurement of the flow of producer-gas, there is the serious danger of the narrow " shunt channel " becoming clogged up. If serious, this difficulty might perhaps be overcome by depositing dust or tar-fog electrically in the upstream pipe of the " shunt channel ": this might be accomplished by mounting an insulated wire in this portion of the pipe and maintaining it near " corona " potential by means of a small high-voltage transformer. Experiments describing the successful cleaning of gas from tar-fog by electrical means have recently been published.[12] The deposition of tar-fog might also be prevented by maintaining the " shunt channel " at a temperature of a few degrees above that of the gas. As it is intended that the velocity measuring wire in the " shunt channel " is to be maintained at temperatures from 50° C. to 100° C. above that of the sur-

[11] An arrangement involving the use of a " shunt channel " adapted to a Venturi tube for the measurement of the flow of liquids has recently been described by Dejust, J., *Comptes Rendus*, 161, Oct. 18, 1915, pp. 456–458.

[12] See note on " Tar Removal " in the *Scientific American Supplement*, May 22, 1915, p. 330.

FIG. 2.



Electrical Recording Venturi Meter Based on the Recording Linear Hot-wire Anemometer.

Fig. 2 *a* shows a general arrangement whereby a linear hot-wire anemometer mounted in the centre of a narrow "shunt-channel" may be adapted to measure the small pressure-difference across a Venturi tube as described in Section 3. Two such "shunt-channel units," S_1 and S_2, are mounted in parallel, as shown in the figure; one of these is intended to be isolated by means of either pair of stop-cocks V_1 and V_2 and employed either as a spare unit to be operated while the other is being examined or repaired, or it can be reserved to check the readings of the working unit. By means of a sensitive Topler manometer connected across the stop-cocks *MM*, the pressure-difference across the Venturi tube may easily be measured in absolute units to 10^{-6} atmospheres. A convenient design suited to the purpose is shown in Fig. 3. From the simple formula (2) applying to a Venturi meter in which the ratio of diameters of cross-sections is maintained as near unity as is consistent with getting an easily measurable flow through the shunt-channel the total rate of flow through the main may be obtained and the readings of the recording ammeter or watt-meter of the recording apparatus calibrated in terms of absolute flow units. In many cases of practical application the varying composition of the gas would require occasional calibrations of the "anemometer" units in absolute measure, so that a Töpler manometer might in these circumstances be included as a permanent part of the apparatus. *C* represents a gas-tight box designed to hold the compensating ratio-coils of the Kelvin double bridge so that they may be exposed to the temperature of the gas being metered, as already explained in the description of Fig. 1. In using this apparatus to measure illuminating gas wire-gauze plugs can easily be inserted in the shunt-channel, as at *GG*, to meet the underwriters' objections to having a heated wire inserted in a pipe directly connected to the mains.

Fig. 2 *b* shows a sectional view of the shunt-channel unit, of which a view from above is shown in Fig. 2 *c*. This unit consists of two main portions, one of which is designed to be inserted into the shunt-line by means of standard couplings. Fitting tightly into this piece, as indicated in Figs. 2 *b* and 2 *d*, is the "anemometer unit," constructed of an insulating material, such as moulded baeklite. Mounted in position so as to lie along the centre of the "shunt-channel," at right angles to the direction of flow, is the anemometer-wire *A*, connected permanently to the current- and potential-terminals C_1C_2 and P_1P_2 respectively.

Fig. 2 *e* shows the method of mounting the anemometer-wire *A* in the shunt-channel.

WW are two springs connected to the terminals C_1C_2. The other extremities terminate in the form of small platinum buttons over which the loops at the ends of the standard anemometer-wires may easily be slipped. The potential leads, permanently fused in position to the anemometer-wire, are connected to the terminals P_1P_2. This mounting is so disposed that the supporting springs are on the down-stream side of the anemometer-wire.

The most suitable temperature at which the anemometer-wire is to be maintained will depend largely on conditions of service and on the nature of the gas which it is desired to measure. In general the temperature should be as high as is consistent with the wire (supposed to be of platinum), not attaining to a temperature of, say, 600° C. in the event of the flow in the shunt-channel being suddenly cut off and the relay-galvanometer (G, Fig. 1 *a*) failing to respond instantaneously to this change of flow.

In its application to the measurement of steam-flow, the shunt-channel unit and Töpler manometer would have to be designed to withstand the necessary pressure: difficulties liable to arise from the "wetness" of the steam might be eliminated by superheating that part of the steam-flow passing through the shunt-channel.

It is hardly necessary to remark that the linear anemometer and recording mechanism may be constructed to operate with alternating as well as with direct current. It may also be noticed that the automatic adjustment of the anemometer-wire to constant temperature above the surrounding gas is unaffected by fluctuations of line-voltage. Hence the recording Venturi meter based on the linear anemometer may be operated from the ordinary direct-current or alternating-current lighting circuit independently of the voltage regulation.

rounding gas, no difficulty is anticipated from deposits being made on the wire itself.

On account of the difficulty just mentioned the method described in Section 2 is to be employed whenever possible in measuring gas flow under conditions involving danger from tar deposits.

In the case of clear gases, however, the writer is disposed to recommend the shunt method in all cases as probably being the more accurate and convenient in practice: this arrangement permits the standardization of the shunts and recording mechanism for all ranges of flows, an important point if the recording meter just described is destined to have extensive application in practice.

Section 4. *Mathematical Theory of the Electric Recording Venturi Meter Based on the Linear Hot-Wire Anemometer.*

We will assume the anemometer-wire to be mounted in the shunt channel (see Fig. *2b*) in which the distance between the walls is $2b$ and the length in the direction of flow l. The dimensions of this channel should be adjusted so that the flow through it under the pressure-difference across the Venturi tube falls within the régime of viscous stream-line flow. If the anemometer-wire be adjusted parallel to the walls of the channel at a distance y from the central plane, the velocity of the gas past the anemometer-wire under the pressure-difference $(p_2 - p_1)$ is given by the equation[13]

$$V = (1/2\mu_o)(b^2 - y^2)\cdot(p_2 - p_1)/l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Combining equations (2) and (3), the rate of mass flow Q through the Venturi tube is given by an expression of the form

$$Q = K_1(\mu_o \rho_o V)^{1/2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

---

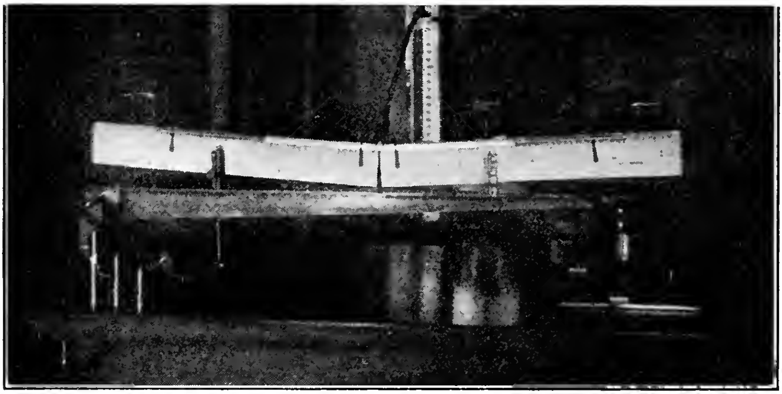
[13] See Lamb, "Hydrodynamics," 1906, p. 542.

where ρ_o is the density and μ_o the viscosity of the gas referred to its temperature θ_o. K_1 is a constant depending only on the fixed dimensions of the Venturi tube and on the adjustment of the shunt channel, as well as on the position (preferably at the centre) of the anemometer-wire in this channel: in terms of these quantities it is given by the relation

$$K_1 = 2A_1 l^{\frac{1}{2}}[(A_1/A_2)^2 - 1]^{-\frac{1}{2}} \cdot (b^2 - y^2)^{-\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Referring now to the writer's theory of the temperature-compensated Kelvin double bridge employed in conjunction with the linear hot-wire anemometer,[14] the current i required to main-

FIG. 3.



A Töpler manometer for measuring minute pressure differences.

tain the wire at constant temperature-difference $(\theta - \theta_o)$ above the temperature θ_o of the surrounding gas is approximately (neglecting radiation from the wire and the variation of the convection constants with the temperature θ_o) given by an equation of the form

$$K_2 i^2 = \gamma_o' + \beta_o' V^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

K_2 is a constant depending only on the resistances (A_o, a_o, B, β) forming part of the Kelvin double bridge, and is given by the relation

$$K_2 = a_o L^{-1}(a_o/A_o - \beta/B)^{-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where A_o is the resistance at 0° C. of the anemometer-wire whose

[14] King, L. V., "On the Precision Measurement of Air Velocity, etc.," *Phil. Mag.*, **29**, April, 1915, pp. 571–572.

length between potential terminals is L. The resistance a_0 (referred to 0° C.) is constructed so as to have the same temperature-coefficient as the anemometer-wire A_0: (B, β) are constructed of manganin and are thus practically unaltered by temperature changes.

β'_0 and γ'_0 are the convection constants of the anemometer-wire referred to the temperature of the surrounding gas, the accented symbols indicating that temperatures are supposed to be expressed in the "platinum scale." Over moderate ranges of temperature (say about 500° C.) these values differ very little from the corresponding quantities referred to the true scale, whose values, according to the theory developed by the writer,[15] are given in terms of the thermal constants of the gas by the relations

$$\gamma_0 = \kappa_0 \text{ and } \beta_0 = 2(\pi s_0 \rho_0 \kappa_0 a_0)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

κ_0 is the thermal conductivity of the gas, s_0 its specific heat per unit mass (at constant volume), while a_0 is the radius of the anemometer-wire. All these quantities are referred to the temperature θ_0 of the gas being measured. From the experiments of the writer on the convection of heat from small platinum wires in air, these theoretical values were satisfactorily confirmed and were found to have small temperature coefficients represented by the equations

$$\gamma = \gamma_0[1 + 0{\cdot}00114(\theta - \theta_0)], \quad \beta = \beta_0[1 + 0{\cdot}00008(\theta - \theta_0)] \quad . \quad . \quad . \quad (9)$$

As experiments in air indicate that the term $\beta V^{\frac{1}{2}}$ of the formula for heat convection is always much greater than the term γ over the range of velocities which it is proposed to measure,[16] we are justified in neglecting the effect of the fluctuations of the gas-temperature θ_0 on the accuracy of equation (6). The same experiments indicate that so long as the temperature is not raised beyond 500° C. the heat-loss by radiation is very small compared to the radiation losses.[16]

Identifying (β_0, γ_0) with (β'_0, γ'_0) over the range of temperature, we obtain from equations (6) and (8)

$$(\mu_0 \rho_0 V)^{\frac{1}{2}} = (K_2 i^2 - \kappa_0)/(4\pi s_0 a_0 \kappa_0/\mu_0)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

According to the Kinetic Theory of Gases, we have the relation

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[15] King, L. V., "On the Convection Constants of Small Platinum Wires, etc.," *Phil. Trans. Roy. Soc.*, 214A, 1914, p. 381.

[16] *Loc. cit.*, Tables V and VI, pp. 420 and 422.

$\kappa_o = f\mu_o s_o$, where f is a purely numerical factor independent of temperature and density, a result which has been verified by experiment, at any rate over moderate ranges of temperature.[17]

We may thus write

$$(\mu_o \rho_o V)^{1/2} = (K_2 i^2 - \kappa_o)/K_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where $K_3 = 2s_o(\pi f a_o)^{1/2}$ is a constant (theoretically) independent of the temperature and density of the gas flowing past the anemometer-wire. It may be noticed here, in view of ultimate practical applications, that Thomas[9] found that the specific heat s_o of illuminating gas remained remarkably constant throughout wide variations in composition: from an inspection of the available determinations of the factor f as well as from theoretical considerations there is reason to believe that this factor will not vary much with varying composition of the gas measured. The thermal conductivity κ_o, in equation (11), is (theoretically) independent of the density, but has a temperature coefficient of the order 0.002 for air: this term is, however, small compared to $K_2 i^2$, so that the variation of this term with the temperature θ_o of the gas will not seriously affect the term on the left-hand side of equation (11). We thus obtain from (4) and (11)

$$Q = K_1(K_2 i^2 - \kappa_o)/K_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

which for experimental purposes may be written more conveniently in the form

$$Q = K(i^2 - i_0^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

In this formula we have seen that there is reason to believe that the constant K will be independent of both temperature and density of the gas being measured, and probably, to a great extent, independent of the relative proportions of the constituents in the case of a mixture of hydrocarbons. The constant i^2_o is (theoretically) independent of the density, but may be expected to vary slightly with temperature. Its value is, however, small compared with i^2 over the working range of the instrument. It should be noticed that i_o is not the current which would actually be observed if the gas-flow in the Venturi tube were completely cut off, as the current required to maintain the anemometer-wire at its constant temperature above the surrounding gas will in these

[17] See Meyer, "Kinetic Theory of Gases" (English translation by Baynes), 1899, 291–296.

circumstances be governed by free convection. By carrying out a series of absolute determinations of rate of mass flow by means of the Venturi tube and Töpler manometer, the constants K and i^2_0 of formula (13) may be determined. A formula of this type can only be expected to give an accurate interpretation of observed results so long as the velocity of flow past the anemometer-wire exceeds a few centimetres per second.

By integrating equation (13) with respect to the time, we notice that the total flow of gas in any interval may be obtained from the readings of an integrating wattmeter. A little consideration will show that it is possible to employ an integrating wattmeter of the Elihu Thomson or Evershed electric motor type in such a way that its readings will be strictly proportional to the integrated mass flow through the Venturi tube. In these instruments the field coils (without iron) carry the main current, while the armature (also without iron) is a fine-wire coil having in series with it a fixed resistance: the two latter are shunted across the ends of the power-absorbing circuit. The armature shaft carries a copper disc which revolves between the poles of a permanent magnet, so that the retarding force due to the eddy currents set up in this disc is proportional to the angular velocity. In the present circumstances we will suppose that in addition to the constant pivot friction we introduce a constant frictional torque easily capable of adjustment. When the armature of the instrument is rotating under steady conditions the torque developed by the current passing through the instrument is, under the present circumstances, proportional to i^2, the voltage terminals being connected across the constant balancing resistance B, Fig. 1b. We may thus write:

$$i^2 = m\,(dN/dt) + n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where N represents the number of revolutions of the armature per second, m is a constant of the instrument, and n refers to the adjustable constant retarding torque. We thus have from (13) and (14) the relation

$$Q = k[m(dN/dt) + n - i_0^2] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

It will be noticed, from this equation, that if we adjust the constant torque so that $n = i_0^2$, that is, so that the armature of the wattmeter just begins or stops rotating for the value of current

i_o (determined by extrapolation)—we have, on integrating (15) over any interval t, the expression

$$\int_0^t Qdt = C(N_t - N_o) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (16)$$

where C is a constant independent of the temperature and density of the gas being measured. Should the term i^2_o in (15) turn out to have an appreciable temperature-coefficient, it should be possible to arrange for the constant torque which is proportional to n to have the same temperature coefficient.

In any case the disposition of apparatus which we have been considering leads to a very promising means of measuring the integrated mass flow of gas in a pipe in any interval of time in such a way that it is proportional to the reading of an integrating wattmeter. The wattmeter readings may be expected to give a true measure of mass flow independently of pressure (and therefore density) fluctuations in the mains and very nearly (if not absolutely) independently of temperature changes.

MONTREAL, February 15, 1916.

An Electric Arc Furnace for Laboratory Use. O. P. WATTS. (*Metallurgical and Chemical Engineering*, vol. xiv, No. 12, June 15, 1916.)—In view of the many electric steel furnaces of the arc type now in operation, and the numerous descriptions of these available, it would seem a simple matter to construct a satisfactory furnace for melting metals in the laboratory. This, however, is not as easy as it appears, and the description in this paper of a laboratory furnace of 10 pounds capacity, capable of producing the easily controlled and measured high temperatures, practicable only with the electric furnace, should prove of rare interest to those whose investigations lie in the domain of high temperatures.

The furnace is of the tilting type and rectangular in shape, measuring 16½ inches long, 14½ inches wide, and 17½ inches high. The melting-pot, measuring 8¾ x 6 x 7 inches, is constructed of magnesia brick, 2¼ inches thick; the insulating material between the pot and the sheet-iron shell is slaked lime. A slab of electrically fused magnesia is used for the roof. The electrodes are 1½ inches in diameter and are supported by inclined brackets so as to meet at an angle of 90 degrees above the furnace charge. The electrode holders are water-cooled and arranged with a screw feed. The total weight of the furnace is 334 pounds, and, exclusive of refractories, the cost was $50.

THE ELEMENT OF CHANCE IN SANITATION.*

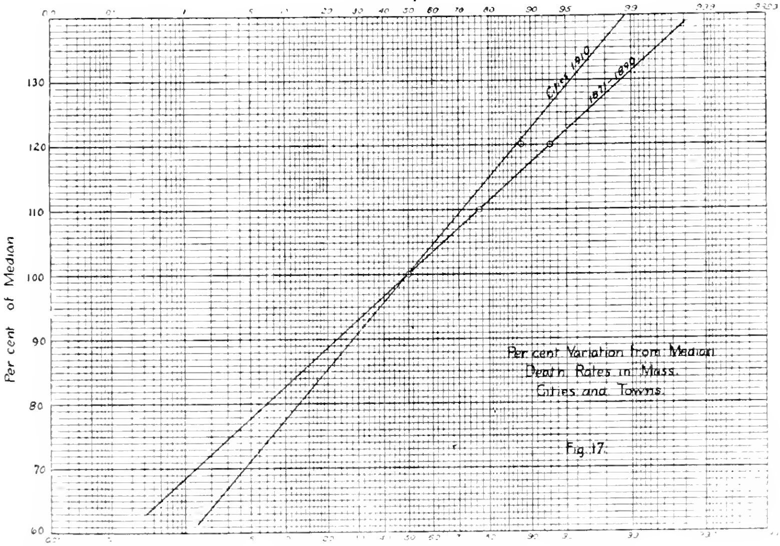
BY

GEORGE C. WHIPPLE, S.B.,

Gordon McKay Professor of Sanitary Engineering in Harvard University.

In studies of vital statistics the attempt is often made to compare death-rates for different years or in different places in the effort to trace the effect of some supposed cause—such, for example, as an improvement in the public water supply or the introduction of a sewerage system or some improved method in public health administration. In making these studies, it is necessary to take into account the fluctuations in the death-rates which are due to many other causes than the ones under investigation. A considerable amount of fallacious reading by sanitarians has resulted from failure to take these variations into account. Here the laws of probability will prove useful.

Fig. 17.



Variations in death-rates plotted on probability paper.

Analyses of Milk.—Fig. 19 shows how the probability paper

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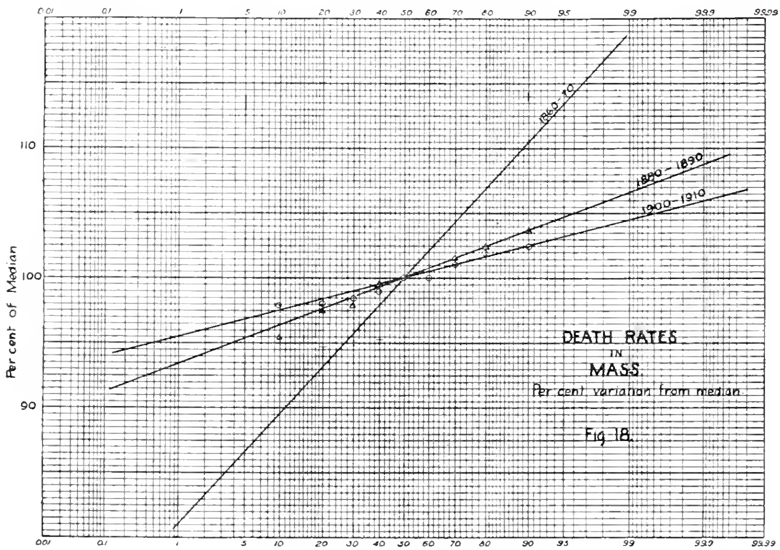
* Presented at the meeting of the Mechanical and Engineering Section held Thursday, March 9, 1916.

* Concluded from page 59 of July issue.

may be used in milk analysis. From the records of analyses made by Mr. Lythgoe in the laboratory of the Massachusetts State Department of Health, it was found that, in the case of a long series of samples, the median amount of solid matter was 12.3 per cent. One sample in every ten contained as high as 13.3 per cent. and as low as 11.4 per cent., while one sample in every hundred contained as high as 14.8 per cent. and as low as 10.3 per cent. It will be noticed that that portion of the curve below 11 per cent. did not follow the other section of the curve. This doubtless indicates a special cause acting on 4 per cent. of the samples. This may perhaps be taken to indicate adulteration in the case of this percentage of samples.

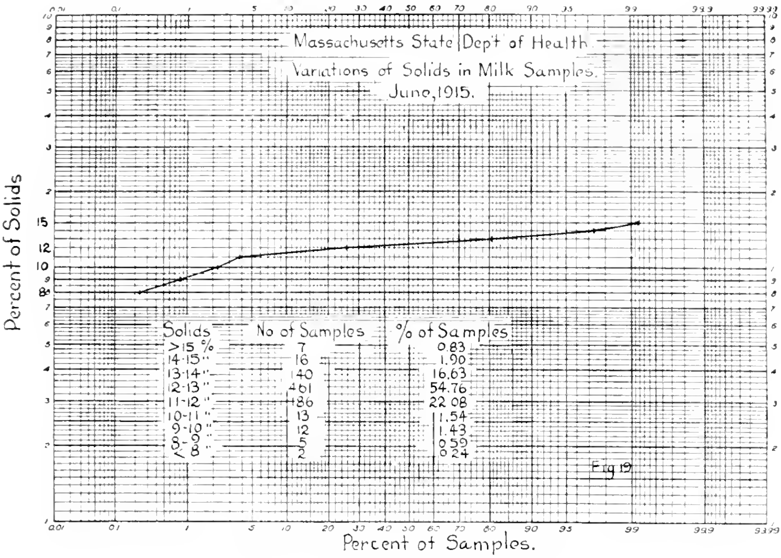
FIG. 18.



Variations in death-rates plotted on probability paper.

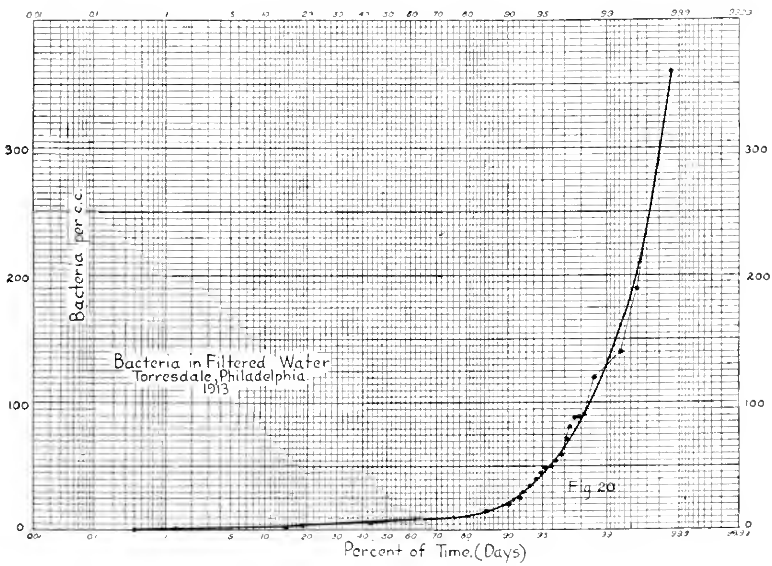
Logarithmic-probability Paper.—In applying the arithmetic-probability paper to certain series of observations, it was found that in some cases the points did not fall upon straight lines, but in curves. An attempt was therefore made to modify the paper by changing the vertical scale. The scheme which proved most successful was to use a logarithmic scale for the ordinates. It was found that, in many cases, points which did not fall in a straight line on the arithmetic-probability paper did fall approximately in a straight line or a gentle curve on the logarithmic-probability paper.

FIG. 19.



Milk analysis plotted on probability paper.

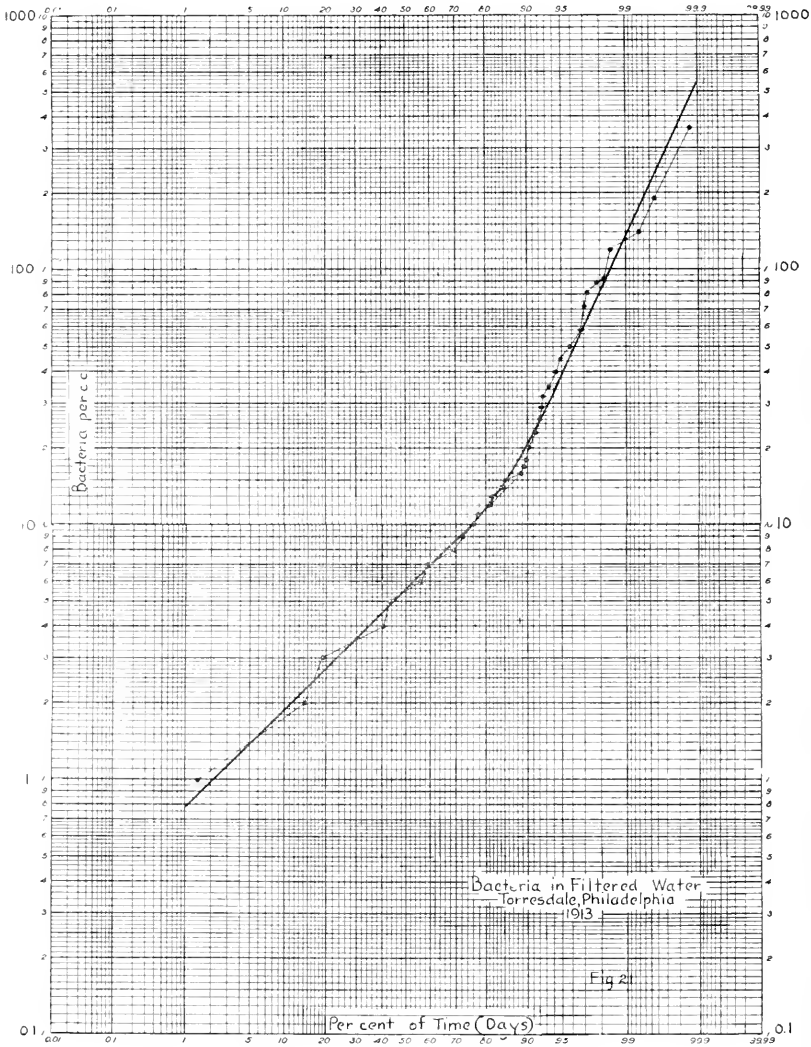
FIG. 20.



Bacteria in filter effluent plotted on arithmetic-probability paper.

An example of this is shown in Fig. 20. Here the number of bacteria in the filtered water from the Torresdale Filter of the Philadelphia water supply was plotted upon arithmetic-probability

FIG. 21.

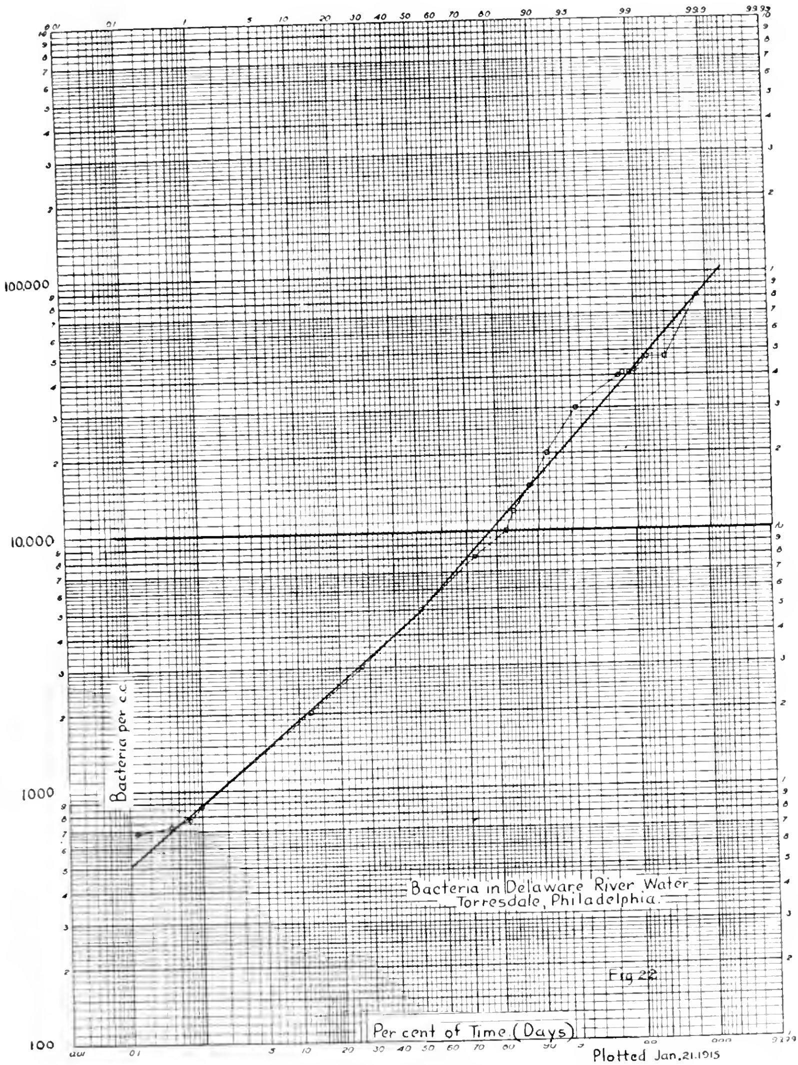


Bacteria in filter effluent plotted on logarithmic-probability paper.

paper, and it will be seen that the points fell along the line of a rather smooth curve. When the same data were plotted on log-

arithmic-probability paper, as shown in Fig. 21, the points fell more nearly on a straight line, but even here the adherence to the

FIG. 22.

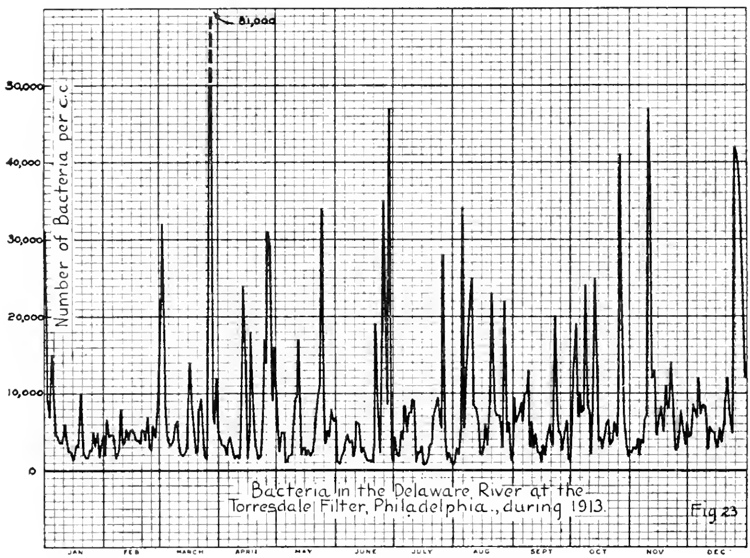


Bacteria in river water plotted on logarithmic-probability paper.

straight line was not exact. The diagram shows, however, that, while the median number of bacteria in a filtered water for the

year was 5.5, the numbers were higher than 100 per cubic centimetre during 1½ per cent. of the time; that is, about 5 days in each year. In the case of the bacteria in the raw water from Delaware River at the Torresdale Filter, the points fell more nearly on a straight line when plotted on logarithmic-probability paper, as shown in Fig. 22. During the year the median number of bacteria in the river water was 4800 per cubic centimetre, but during 10 per cent. of the time the numbers were higher than 16,000 per cubic centimetre, and during 1 per cent. of the time they were higher than 41,500. On the other hand, during 10 per cent. of the time the numbers in the raw water were less than 1900, and during 1 per

FIG. 23.

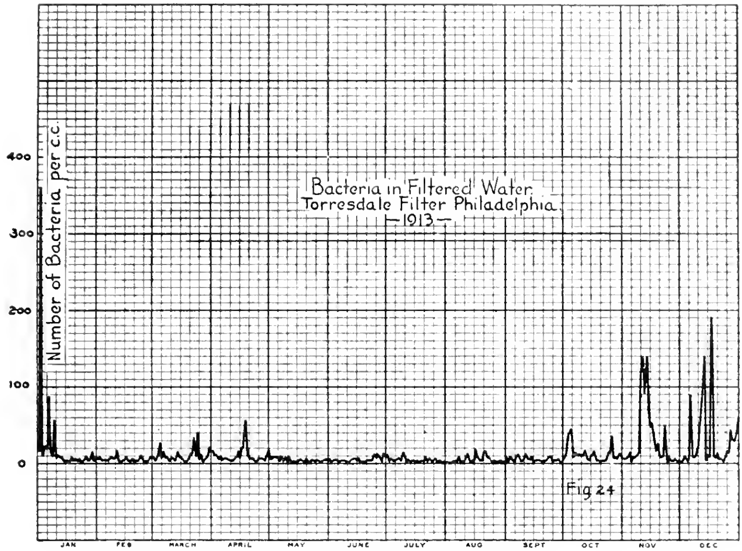


Variations of bacteria in river water.

cent. of the time less than 870. This method of plotting serves to bring out the frequency of certain observations more strikingly than in the case of ordinary plotting in a chronological manner. The ordinary method of showing the results is shown in Figs. 23 and 24.

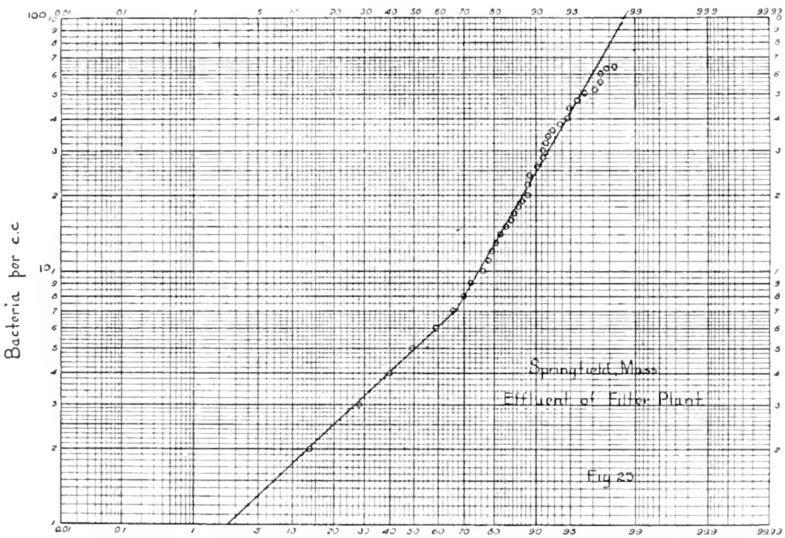
Fig. 25 shows the results of plotting the number of bacteria in the filtered water of the Springfield (Mass.) Filter for the year 1913. In this case the results do not fall exactly on a straight

FIG. 24.



Variations of bacteria in filter effluent.

FIG. 25.

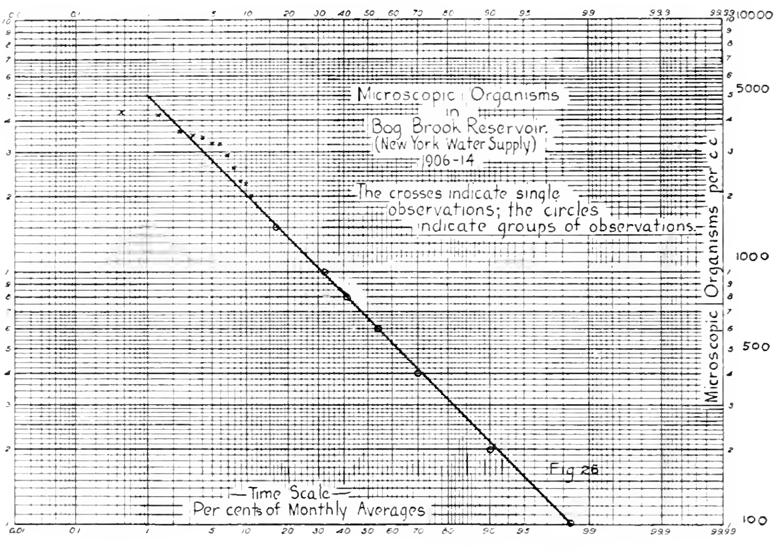


Bacteria in filter effluent plotted on logarithmic-probability paper.

line, but the line drawn shows that the median number in the filtered water was 5 per cubic centimetre; that 10 per cent. of the samples contained more than 25 per cubic centimetre and 1 per cent. more than 200. These results show the filtered water at Springfield to be slightly lower in bacterial content than the filtered water at Torresdale. The difference, however, is not marked.

It has been found also that the algæ and other microscopic organisms in the water of a given reservoir may be plotted as a straight line, or nearly so, on logarithmic-probability paper. This is illustrated in Fig. 26, which shows the microscopic organisms in Bog Brook Reservoir of the New York water supply for the years 1906–1914. During this time the median number of organisms

FIG. 26.



Microscopic organisms plotted on logarithmic-probability paper.

observed was 650 per cubic centimetre, but during 10 per cent. of the time they were higher than 2000, and during 1 per cent. of the time higher than 5000 per cubic centimetre. During 10 per cent. of the time they were lower than 215, and during 1 per cent. of the time lower than 70 c.c.

In order to use the probability paper it is not necessary that the plotted points should fall exactly on a straight line. If the curve is so gentle and uniform that it may be extended somewhat beyond the limits of the plotted points, it will usually be found sufficient.

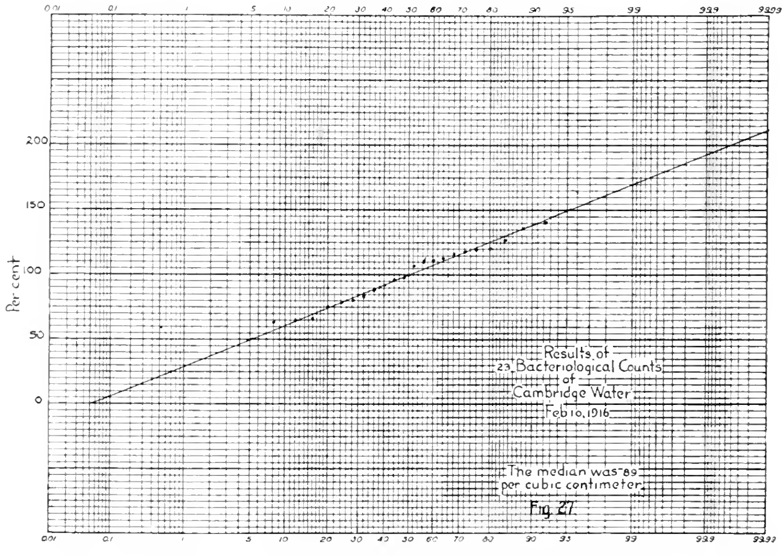
Bacterial Counts in Water.—It is a fact well known to bacteriologists that the quantitative methods of determining the number of bacteria in water, milk, and other liquids are far from accurate. Duplicate determinations seldom agree, and, even when three or more determinations are made with the same samples, there is found to be a very large percentage of error. There are various reasons for this. The ingredients of the culture media are themselves not uniform. The peptone, gelatin, beef-broth, beef-extract, and the like are biological products, and when cooked together the resulting culture medium cannot, in the nature of the case, always be the same. Furthermore, the temperature of incubation, the physical character of the media, the moisture of the air within the Petri dishes are all subject to variations, while differences in the bacteria themselves contribute to the inaccuracy of the result. Liquefiers in gelatin and spreaders in agar play an important part in rendering the results unreliable. In spite of all that the best bacteriologists have been able to do in standardizing methods, it remains true that the precision of the quantitative bacteriological work done to-day is but little in advance of that which was done 25 years ago. Recent attempts to establish standards for waters served by common carriers, for effluents of water filtration plants and sewage treatment works, for shell-fish and other food products are bringing to a crisis some of these matters which relate to the accuracy of quantitative bacteriological results. It is becoming evident that if numerical quantitative standards are to be used and strictly applied it is necessary to have them based upon more accurate methods and more frequent sampling than those now at hand, and that, unless this is done, the numerical standards must be made sufficiently lenient to allow for occasional results which lack in precision. In studying this question the laws of probability may be found useful.

Recently a sample of tap water in Cambridge, Mass., was subjected to repeated bacteriological examination in order to ascertain the precision of the results. The numbers of bacteria were first determined in the usual way on gelatin plates, incubated for 48 hours at 20° C. Twenty-five tests were made, but two of the plates were thrown out because of accidental contamination. The remaining 23 plates were counted and the results studied statistically. The numbers of bacteria varied in the different plates from 57 to 123. The average count was 88 and the median 91. The minimum count was 65 per cent. of the mean, and the maximum

count was 140 per cent. of the mean. When the results were plotted on arithmetic-probability paper, the points fell nearly in a straight line, as shown in Fig. 27. A line drawn through these points indicated that one plate in every ten differed from the median by about 40 per cent., while one plate in every hundred differed from the median by 70 per cent.

Again, 27 plates were made for Cambridge tap water using agar and incubating for 24 hours at 37° C. The mean of these results was 14 bacteria per cubic centimetre, the median 13, the maximum 23, and the minimum 7. In spite of the small numbers, these results, when plotted on probability paper, fell approxi-

FIG. 27.



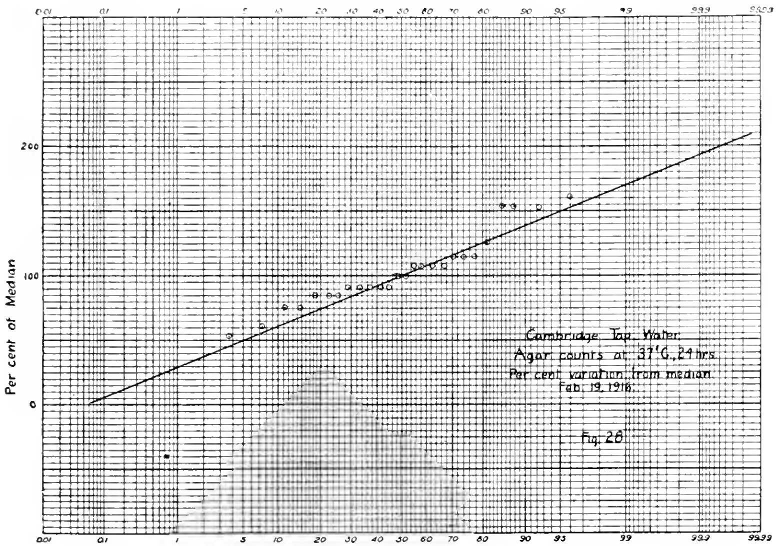
Variations of bacterial counts plotted on probability paper.

mately on a straight line, and, as before, this line showed that one plate in every ten differed from the median by 40 per cent., while one plate in every hundred differed from the median by 70 per cent. (Fig. 28).

These results cannot, of course, be taken to represent the precision of bacteriological counts in all laboratories, made under all conditions. They do, however, illustrate the inaccuracy of the method when applied twice under standard conditions with all possible care.

The bearing which this has on standards of purity is important. Let us assume that a bacteriological standard of 100 bacteria per cubic centimetre has been established, as a permissible limit, and that the precision of the method is that indicated by the line drawn in Fig. 27. If water submitted to this test actually contained 50 bacteria per cubic centimetre, the chance of a single plate count showing less than 100 per cubic centimetre (*i.e.*, 200 per cent. of the actual) would have been 99.96 per cent., and the chance of its showing more than 100 per cubic centimetre would have been 0.04 per cent., or 1 in 2500. If the water contained only 25 bacteria per cubic centimetre, the chance of a single plate showing

FIG. 28.



Variations of bacterial counts plotted on probability paper.

100 would have been vastly less, but the diagram is not extended far enough to determine the chance. If the water contained 75 bacteria per cubic centimetre, the chance of a single plate showing less than 100 per cubic centimetre (*i.e.*, 133 per cent. of actual) would have been 86 per cent., and the chance of a single plate exceeding 100 per cubic centimetre would have been 14 per cent., or about 1 in 7. The following figures show the chance of a single bacteriological count exceeding a given standard of 100 when the

actual number present in the sample is the figure given in the first column:

Number of bacteria present	Chance of a single sample exceeding the standard of 100
100	1 in 2
90	1 in 2.8
80	1 in 5
70	1 in 12.5
60	1 in 66.6
50	1 in 2500

On the other hand, in a sample of water which contained more bacteria than the standard, there would have been a chance that the plate contained fewer bacteria than the standard, and this chance is indicated by the following figures:

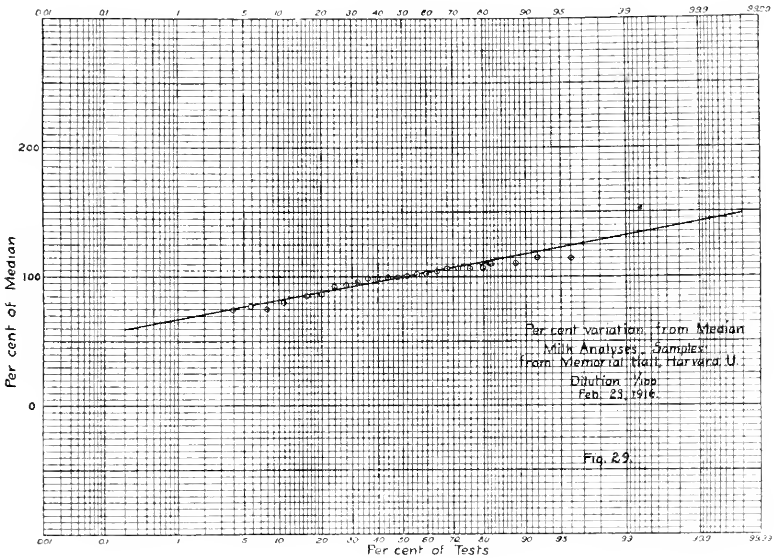
Number of bacteria present	Chance of a single sample being less than the standard of 100
100	1 in 2
110	1 in 2.6
120	1 in 3.4
130	1 in 4.5
140	1 in 6.1
150	1 in 7.7
200	1 in 20

It will be seen from these figures that in the case of waters which contain fewer bacteria than the standard, but near it, the chance of a single count exceeding the standard is high, but in samples which contain much fewer numbers than the standard the chance of a single count exceeding the standard decreases rapidly. In the case of samples which contain more bacteria than the standard the chance of a single count showing less than the standard is considerable. The chance of a bad sample being called good is greater than the chance of a good sample being called bad if the number of bacteria present differs greatly from the standard.

It is evident that when dependence is placed upon a single bacterial count a rigid application of the standard is likely to do injustice either on one side or the other. According to the laws of chance, the probability that two independent events will happen simultaneously is equal to the product of the probabilities of each happening alone. Thus in the case of a water containing 80 bacteria per cubic centimetre the chance of one plate showing more than 100 bacteria is 1 in 5, but the chance of two plates showing more than 100 is 1 in 25, and the chance for three plates giving

more than 100 is 1 in 125, etc. It is evident, therefore, that in order to prevent injustice being done in the application of quantitative bacteriological standards to water it is necessary that several tests should be made. The number of plates which should be made in any given case has not been definitely determined, but, obviously, a large number of plates should be made whenever there is reason to suspect that the water approaches a given standard in its bacterial content. For waters which are expected to be far below the standard two plates would probably be sufficient, but under many conditions five or even ten plates may be necessary to give results which can be safely depended upon.

FIG. 29.



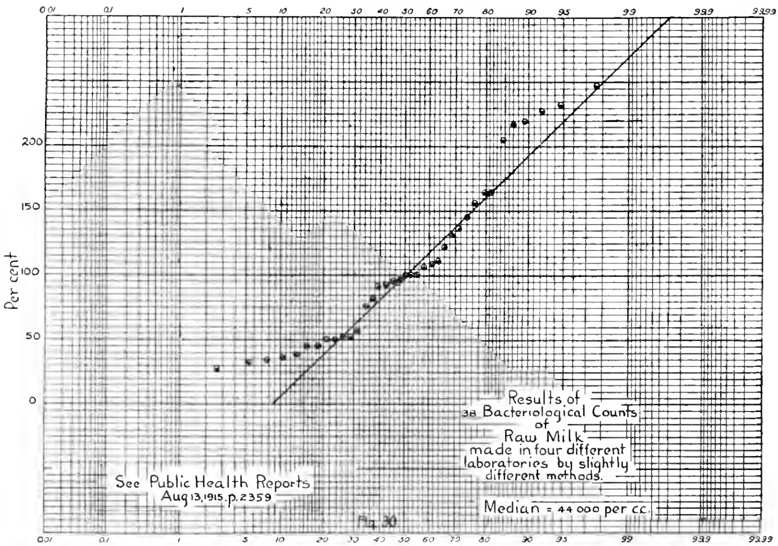
Variations of bacterial counts in milk sample plotted on probability paper.

Bacterial Counts for Milk.—Fig. 29 shows the results of bacteriological examinations of a sample of milk sold in Cambridge, February 24, 1916. Standard methods were used, the culture medium being agar and the dilution 1 to 100. Twenty-five determinations were made. The maximum plate gave 112,000 bacteria per cubic centimetre, the minimum 70,000, the median 94,000. The probability line shown in Fig. 30 indicates that one sample in ten differed from the median by 18 per cent., and one sample in 100 differed from the median by 33 per cent.

It seems obvious that to enforce a strict numerical bacteriological standard for milk or water, based upon methods of analysis, themselves subject to error, is unscientific and, it may be, unfair, unless the regulations also prescribe the frequency of sampling. And one may go further and say that such numerical standards should also take into account the natural variations in the numbers under conditions which may be regarded as safe.

This may temporarily upset the work of certain health departments, but in the end will contribute justice to all concerned. On the basis of these figures it might be said that the bacterial counts

FIG. 30.



Variations of bacterial counts in milk sample plotted on probability paper.

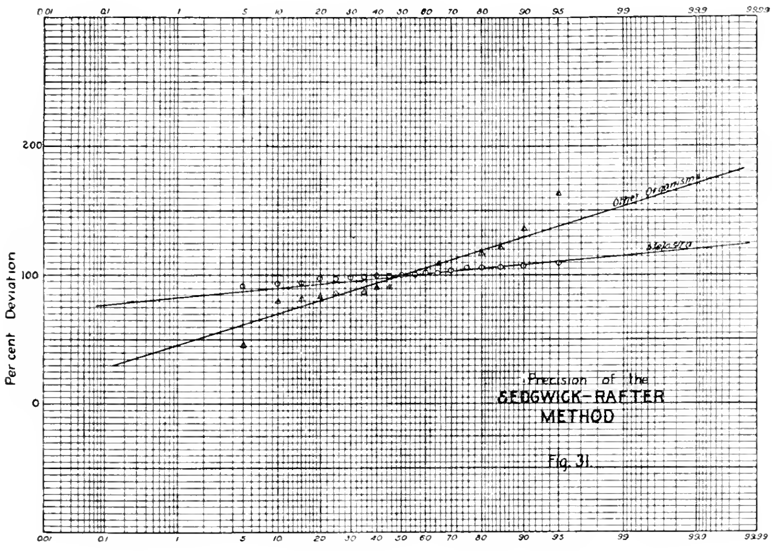
for milk were more precise than for water. It would not do to make this statement, however, on the basis of a single determination made by one person using the same medium under rigid standard conditions. Furthermore, figures given by Professor Conn [4] show a different result. To take one instance: 38 bacteriological examinations of raw milk made in four different laboratories by methods which differed slightly, but all of which are likely to be used, gave results which are shown in Fig. 30. The median of these results was 44,000 per cubic centimetre, the

[4] *Public Health Reports*, August 13, 1915, p, 2359.

minimum 12,000, and the maximum 115,000. These points did not fall as nearly upon a straight line as the preceding. The probability line showed that one plate in every ten was likely to be 90 per cent. above the median result, while one sample in every hundred was likely to exceed the median by 140 per cent.

It is quite evident from these two probability lines that there is much yet to be learned in regard to the precision of bacterial counts in milk. It is evident, however, that the results lack in precision, and this is a factor which must have an important bearing on the application of bacterial standards of purity to milk.

FIG. 31.



Variations in counts of microscopic organisms plotted on probability paper.

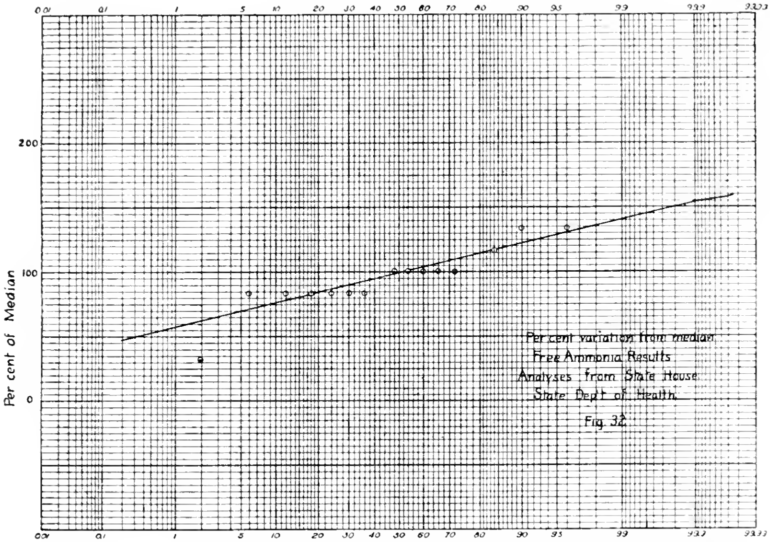
Precision of Sedgwick-Rafter Method.—The precision of determinations of microscopic organisms in water is illustrated by Fig. 31, which shows the result of examinations made for a sample of Cambridge tap water, February 19, 1916, by Mr. Wells of the Water and Sewage Laboratories of Massachusetts State Department of Health. Two lines are drawn, one for Melosira, which happened to be present in large quantities, and one for Miscellaneous Organisms, which include Asterionella, Cyclotella, Cœlospærium, Protococcus, Chlamydomonas, Glenodinium, Peridium,

Tintinnus, and Trachelomonas. The median number of these Miscellaneous Organisms was 100 per cubic centimetre, while the median number of Melosira was 4907 per cubic centimetre. It will be noticed that the determinations for the Melosira were quite precise. One determination in every ten differed from the median by only 7 per cent., and one determination in 100 by 15 per cent., whereas in the case of Miscellaneous Organisms few in number one determination in ten differed from the median by 30 per cent., and one determination in 100 differed from the median by 103 per cent. When these figures are compared with the results of the bacteriological counts, it is seen that the method is more precise when large numbers of organisms are present. The figures given, however, are merely illustrative and are not to be taken as representing the precision of the method under all conditions. When the green algæ are present the precision is probably much less, because it is necesary to estimate their volume in terms of the standard unit, whereas in the case mentioned above the actual numbers were counted.

Precision of Determinations of Free and Albuminoid Ammonia and Oxygen Consumed.—In order to ascertain the precision of chemical determinations of free and albuminoid ammonia and of oxygen consumed, as used in the analysis of water, Mr. Fred. B. Forbes, assistant chemist of the Massachusetts State Department of Health, recently made 16 duplicate analyses of a sample of Boston tap water, collected February 14, 1916. In the case of the free ammonia, the mean of the 16 analyses was 0.012 part per million and the maximum deviation from the mean was 0.004. The results, when plotted on probability paper, indicated that one sample in every ten exceeded the median by 22 per cent. and one sample in every 100 by 40 per cent. In the case of albuminoid ammonia, the mean was 0.118 part per million and the maximum deviation from the mean was 0.016. The probability line showed that once in ten times a determination exceeded the median by 8 per cent. and once in 100 times by 15 per cent. In the case of oxygen consumed the mean of the 16 determinations was 3.3 parts per million, and the maximum deviation from the mean 0.3. The probability line showed that once in ten times a determination exceeded the median by 7 per cent. and once in 100 times by 14 per cent (see Figs. 32, 33 and 34).

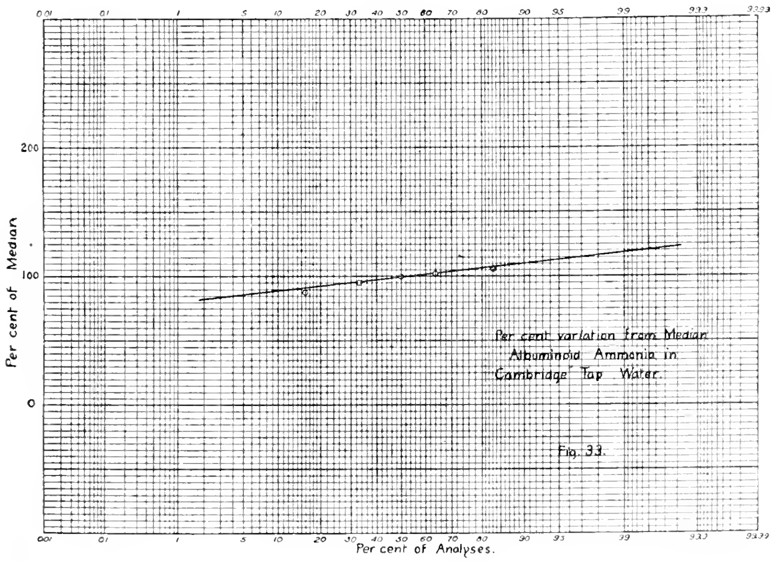
Similar determinations of albuminoid ammonia and free am-

FIG. 32.



Variations in determinations of free ammonia in water plotted on probability paper.

FIG. 33.

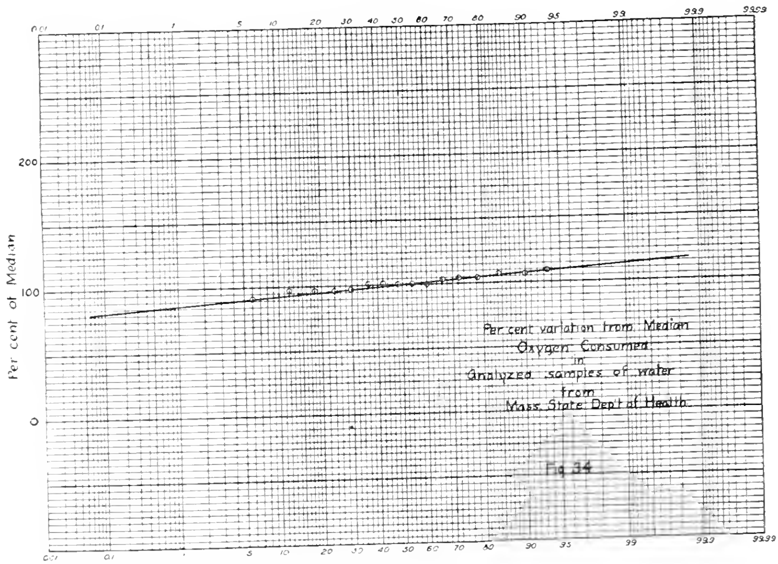


Variations of determinations of albuminoid ammonia in water plotted on probability paper.

monia were made for the Cambridge tap water by Mr. Melville C. Whipple in the Laboratory of Sanitary Engineering, Harvard University. The results were strikingly similar to those which were obtained by Mr. Forbes. When these figures for the chemical analysis of water are compared with those for the bacteriological analysis of water, it is found that the former are far more precise. Greater weight may, therefore, be given to a single chemical analysis than to a single bacteriological examination.

Sand Analysis.—Those who are familiar with sand analysis

FIG. 34.



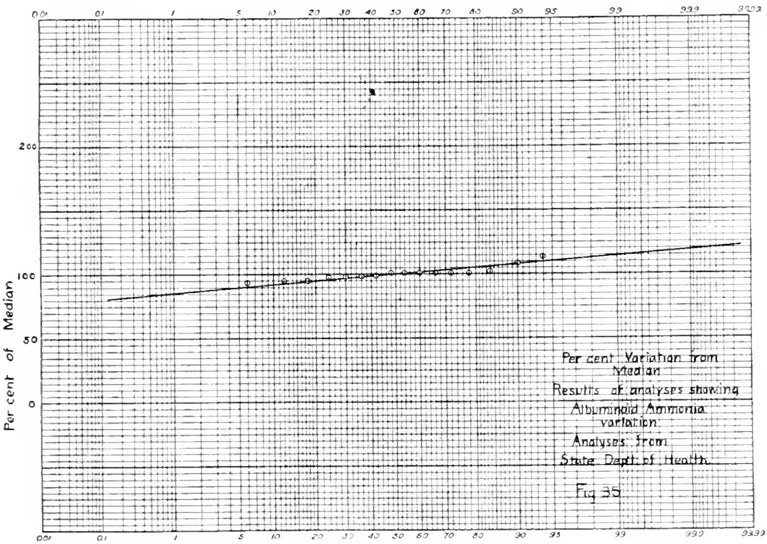
Variations in determinations of oxygen consumed in water plotted on probability paper.

will recognize that the method of sorting sand grains by size and plotting them on sand-analysis paper is substantially a statistical study of the sand grains of different size. On sand-analysis paper the abscissæ are plotted as percentage of weights, while ordinates represent the diameters of the sand grains. The effective size is virtually the lower decentile of the series. The uniformity coefficient of the sand analysis might have been made by comparing the lower decentile with the median, but instead it was made by comparing it with that diameter of grain which was exceeded by 40 per cent. of the weight of the grains. There were good and

sufficient reasons at the time for the adoption of this plan, and it would probably be unwise to change the terminology at this time, as both engineers and contractors are becoming familiar with it. On the other hand, it should be noted that as good a result, and perhaps a better result, might have been obtained by using the theory of probability.

Application of the Probability Curve to Filter Effluents.—For many years it has been customary for sanitary engineers to express the efficiency of filter plants in terms of the percentage of bacteria

FIG. 35.



Variations in determinations of albuminoid ammonia plotted on probability paper.

removed from the raw water. In the early days of filtration, when interest was focussed upon the mechanism to be employed and the choice of different types of filtration for different kinds of water, this method had much to be said in its favor. It was customary to make tests extending over a limited period of time for the purpose of determining the capability of the filter to satisfactorily purify the water. It was a test of the mechanism.

As time has gone on and the devices employed for filtration have become better known and, to a certain extent, standardized, emphasis has been shifted from the capability of the filter to pro-

duce satisfactory results under conditions of test to the question of sustained operation and the ability of the filter and filter operatives, working together, to produce a water safe and satisfactory at all times. It is being recognized more and more that the old method of expressing the efficiency of a filter plant in terms of percentage removal of bacteria is inadequate, and that some new standard of efficiency is needed which will involve the element of time. It is realized that, within certain limits, slight differences in the percentage removal of bacteria have little or no influence on the real hygienic quality of the water. It is also recognized that with any filter plant there may be a few hours or a few days in the course of the year when the analysis is not satisfactory. This is usually shown by a wide divergence of the analyses from the normal condition. This is sometimes due to errors in the analyses themselves. From the hygienic standpoint the important thing is to determine the frequency and amount of these departures from the conditions of normal operation.

The New England Water Works Association Committee on Standard Methods of Reporting Filter Statistics recognized this need and has taken a step towards it by requiring a statement as to the percentage of time during which the numbers of bacteria in the filtered water were found to be between certain given limits. This, however, is only a step in the right direction, and it is hoped that after the subject has been more thoroughly considered by analysts and engineers some simple method of presenting the facts may be worked out. It seems to the writer that this should be based on the law of probability. This new standard might be somewhat similar in form to the present methods used in sand analysis.

It is too early at present to establish any standard of this kind. This cannot be done until the results for the various filter plants of the country have been collected and studied statistically. My partner, Mr. Francis F. Longley, has made a beginning of such a study, and, speaking generally, the results show that in well-ordered filter plants the median bacterial count for the filtered water is usually less than 20 per cubic centimetre, while during 95 per cent. of the time the bacterial counts are less than 100 per cubic centimetre. Whether 95 per cent. or 90 per cent. or 99 per cent. of the time should be selected as a point for establishing a standard remains to be determined. It would seem, however, that if some figure were established for the median and some other

figure which limited the number during 95 per cent. of the time or less, the combination would give a far better idea of the results of filtration than the old method of using "percentage removal."

Application of Chance to Tests for B. Coli.—Our bacteriological tests of water for *B. coli* are somewhat similar to the drawing of a red ball in one or more trials from a certain number of red balls mixed indiscriminately with a certain number of white balls. Out of a certain number of cubic centimetres of water (the sample) we test one cubic centimetre or some other small quantity to see if it gives certain reactions indicative of the presence of *B. coli.* It either does or it does not; the result is either positive or negative; we have drawn a red ball or a white ball.

Mr. M. H. McCrady,[5] in an excellent article on the interpretation of the results of tests of *B. coli,* has assumed that the laws of probability may be applied in this way, and has deduced some convenient methods of estimating the most probable number of *B. coli* which will produce certain given fermentation-tube results. He says, in substance: "Let us assume that our sample is 100 c.c. and that one cubic centimetre is tested. If one *B. coli* is present in 100 c.c., the chance of its being found in 1 c.c. is one in 100, or 0.01; the chance of its being absent is 99 in 100, or 0.99.

"If there are two *B. coli* in 100 c.c., there are two ways in which the test may be positive; *i.e.,* either one or both may be found in the portion tested, but the reaction will be the same in either case, and we cannot tell whether one or both are present. If the result is negative, however, we know that both are absent. The chance of both being absent is equal to the product of the chances of each being absent, or 0.99×0.99 (*i.e.,* $(0.99)^2$) $= 0.9801$. The chance of a positive test is, of course, 0.02. If there are three *B. coli* present, the chance of the test being negative is $(0.99)^3$, or 0.9703. The chance of the test being positive is 0.03. And, in general, if the number of *B. coli* present in 100 c.c. is x, the chance of a negative result is $(0.99)^x$ and of a positive result $1-(0.99)^x$. Let us suppose the number of *B. coli* present to be one in each cubic centimetre; *i.e.,* $x = 100$. In this case it might at first be supposed that the chance of a positive result would be 1.0, or certainty. But, not so, because more than one may be present in a single centimetre and perhaps absent from the centimetre tested. From the

[5] "The Numerical Interpretation of Fermentation-tube Results," *Journal of Infectious Diseases,* vol. 17, No. 1, July, 1915, p. 183.

formula $1-(0.99)^x$, when $x=100$, we find the probability of a positive test to be 0.64; that is, if there were 100 bacteria per 100 c.c. of water, only two-thirds of the 1-c.c. portion tested would give positive results—assuming this method of reasoning to be correct."

Before using his method it is fair to consider carefully as to whether his fundamental assumptions are correct. Is it true that the analogy between the red and white balls and the distribution of *B. coli* in the portions of the sample selected for test is perfect? In the writer's opinion, the cases are not sufficiently similar to enable the laws of chance to be strictly applied. The laws of chance are based on the fundamental idea that the sum of the probability of an event happening and the probability of the event not happening is unity. This is not quite true in *B. coli* tests, for two or more *B. coli* in a single cubic centimetre give the same result, a positive test. Furthermore, bacteria are almost infinitely small as compared with a single cubic centimetre, and there is much more chance that they may be uniformly distributed through the sample and less chance that several would be concentrated in one of the cubic centimetres abstracted from the sample for test than in the case of a mixture of balls, red and white. The so-called anomalies in *B. coli* tests, where a 10-c.c. portion gives a negative result at the same time that a 1-c.c. portion gives a positive result, indicate a certain amount of chance distribution through the volume.

The attempts to interpret the results of *B. coli* tests made by Phelps, Longley, and the Committee of the American Public Health Association on the Examination of Shell-fish, of which the writer was chairman, were based on the concept of a uniform distribution of bacteria through the sample of water. McCrady assumed a distribution such as would occur in a mixture of a few red balls with many white balls. Neither assumption would appear to be entirely correct. An intermediate condition prevails, but at present no one can say which idea is more nearly correct. McCrady's method, however, appears to involve a fallacy which invalidates it, but his work is nevertheless useful in suggesting a stricter use of the laws of probability than has heretofore prevailed. Herein lies a fruitful field for experimental investigation by bacteriologists.

Conclusions.—One might continue to enumerate the applications of the laws of probability almost indefinitely, but perhaps

enough has been said to show that this branch of mathematics can be profitably used by the engineers, chemists, and health officers as well as by the biologists. Oftentimes direct results may be obtained by using the laws of chance, but perhaps the greatest benefit to be derived from the study of probability is the state of mind which it is likely to produce. A realization of the fact that oftentimes many different causes are involved in the production of an event will prevent one from being too sanguine in drawing conclusions from tests, analyses, and statistical data of all sorts, and from being too drastic in the enforcement of standards.

It is believed that in the probability paper which has been described Hazen has given to the profession a new and very useful tool. Heretofore the laws of probability have been used with difficulty; hereafter they may be used with greater facility.

A Cast-steel Wheel with Manganese Tread and Flange. ANON. (*Electric Railway Journal,* vol. xlviii, No. 2, July 8, 1916.)—A one-life, cast-steel wheel with a manganese steel tread and flange and a ductile steel plate around the hub has recently been introduced in the electric railway field by the American Steel Foundries of Chicago, Ill. The product is known as the Davis steel wheel, and its first cost approximates that of a rolled-steel wheel. Its wear life, however, is similar to the wear life of a cast-steel wheel, or even better, because of the tough wheel-tread and flange produced by manufacturing them of manganese steel. The method by which the two kinds of steel are incorporated in one casting was devised especially for the manufacture of the Davis steel wheel. It includes revolving the mould, in which the first metal entering is treated with ferro-manganese during its passage from the ladle into the mould, when the centrifugal action throws it to the wheel-tread and flange. As the pouring continues, the manganese steel rim is gradually blended into a ductile steel plate and hub by tapering off the ferro-manganese treatment.

The advantages claimed for this wheel are that it retains the one-wear principle of the cast-iron wheel and at the same time secures greater strength, safety, and lower maintenance cost. It also avoids the disadvantages of a rolled-steel wheel introduced by turning, which must be followed by adjustments in the bearings and brake rigging whenever the wheels are changed. The extraordinary strength and resistance to wear obtained by the combination of metals in the Davis steel wheel make it possible to produce them in weights lighter than could be obtained in any other metal.

Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds. A. E. KENNELLY and O. R. SCHWIG. (*Proceedings of the American Institute of Electrical Engineers,* June 27–30, 1916.)—The object of this research was to determine the resistance offered by level urban roads of different surface varieties to an electric truck at standard truck speeds not exceeding 25 kilometres (15.5 miles) per hour. The truck used in the tests is of the type commonly used for city and suburban parcel-delivery service, having a load capacity of 1000 pounds and a total weight of 1910 kilogrammes (4200 pounds), with a single reduction worm drive. For this purpose the output of the storage battery was measured for both directions of travel over standard road-beds at different controller speeds. From this output were deducted all the corresponding electrical and mechanical losses in the truck mechanism as determined by laboratory tests. The remainder of the output was consequently attributed to (1) road-, (2) air-, and (3) wind-resistance.

With solid rubber tires and speeds varying between 13 and 25 kilometres (8 to 15.5 miles) per hour, the overall efficiency between the battery terminals and the rear-wheel treads reached a maximum value of 78 per cent. under favorable conditions. The mechanical efficiency from the motor to the rear-wheel treads was found to be as high as 90 per cent. The total range of tractive resistance in equivalent grade was from 0.93 per cent. on the best asphalt road, at lowest speed, to 2.7 per cent. on the worst macadam road at nearly the highest speed.

Magnesium. W. M. GROSVENOR. (*Proceedings of the American Electrochemical Society,* April 27–29, 1916.)—Magnesium finds its chief uses as an alloy with other metals and as an intense illuminant of short duration. Alloying itself with aluminum or aluminum containing traces of one or more other metals, it greatly modifies their crystallization and physical properties. It alloys readily with most metals and melts at a convenient heat. As a scavenging alloy, it clears up oxide of other metals, making far denser, cleaner, and stronger and more homogeneous alloys. Because of its intense avidity for both oxygen and nitrogen, it is valuable in aluminum, nickel, copper, brass, etc., and in special steels. In aluminum castings, for instance, less than 2 per cent. of magnesium cleans the metal and leaves 3/4 to 1 1/2 per cent. in the casting, about doubling its tensile strength, quadrupling its resistance to shock and jar, and producing a much more easily machined metal. As an illuminant for military uses, it is extensively employed for shrapnel trailers, star bombs, flare-lights, etc., and in photography, for flash-lights. Large quantities are consumed in the manufacture of illuminating bombs and trailers for night firing. For these purposes magnesium produces a result that cannot be approached by antimony or aluminum.

THE FUTURE OF CHEMISTRY IN THE HIGH SCHOOL.*

BY

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1. *The Present State of the Methods of Chemical Instruction.*

THERE is much justification for the current indifference shown by many teachers toward the general theory[1] of the learning process. Educational speculation is an undifferentiated product, in which the valuable contributions of sincere thinkers are mingled with the voluminous nonsense of the lay critic, and with the distorted statements of intellectual acrobats who are trying to struggle into the spotlight by exploiting some phrase which happens to have caught the attention of the multitude. As Professor James remarks—in quite another connection—the result is that we "feel it all as one great blooming, buzzing confusion."

However, contempt for theory is an undesirable attitude on the part of any craftsman or artist, for theory is usually intensely practical. Teaching is a very old profession, and it is most unlikely that ages of occupation with it have produced no valuable deposit. The teaching of chemistry, on the contrary, is a novelty by comparison. Laboratories in the universities date only from the work of Liebig at Giessen; in the high school they are a thing of yesterday. While the teaching of Latin and of the mathematical branches is probably on a reasonably permanent basis so that evolution, but not revolution, may be expected, the methods of teaching chemistry have hardly taken shape at all as yet.

The inchoate condition of methods of chemical teaching—and let me insist that this is wholly natural, and is due simply to the newness of the subject in the schools—is most manifest in the

* Communicated by the Author.

[1] I have elsewhere remarked that this word is used in so many diverse senses that it is desirable either to drop it or to standardize its meaning. In the present paper the word "theory" is used to denote the more abstract portion of a subject; that which is reached rather by reflection than by immediate apprehension.

fact that the text-books still handle the subject by the *analytical* method, a plan which has run through its devastating career in most non-scientific subjects, and which, like the measles and the mumps, is distinctly a disease of childhood. That is to say, the book analyzes the subject into its logical elements. These, for our science, would be electron, atom, molecule, matter, energy, solid, liquid, vapor, phase, crystal, substance, and so on. These are then defined in such a way as to make it possible for the child to pretend that he understands them. If the method was employed in a thorough-going fashion the periodic law, also, as a highly general concept which could "usefully be employed later," would be expounded at the outset. The residue consists in the formal treatment of the subject-matter according to these categories, the familiar applications of which come last in order.

Instead of offering any comment of my own on this inverted procedure, let me intercalate a paragraph from John Dewey, who sums up the matter in a masterly way:

> What is conventionally termed logical (namely, the logical from the standpoint of subject-matter) represents in truth the logic of the trained adult mind. Ability to divide a subject, to define its elements, and to group them into classes according to general principles represents logical capacity at its best point reached *after* thorough training. The mind that habitually exhibits skill in divisions, definitions, generalizations, and systematic recapitulations no longer needs training in logical methods. But it is absurd to suppose that a mind that needs training because it cannot perform these operations can begin where the trained adult mind stops. *The logical from the standpoint of subject-matter represents the goal, the last term of training, not the point of departure.*

As a matter of historical fact, the analytical method gives most unsatisfactory results in practice. Its prevalence is followed by a reaction which goes to the opposite extreme. All logic, all abstract thinking, all generalization are to be excised. The stress is to be laid upon the mental habits and predispositions of the student, and upon his environment outside of school. It is most interesting to note that this reaction against the analytical method in high-school chemistry is just now in full swing. We are to "cut out the theory from the subject," the term "theory" being employed apparently as a convenient inclusive designation for anything which necessitates vigorous reflection. The retort, the beaker, and the balance are to be cast out and "mother's oven," the tea-kettle, and the nutmeg-grater substituted as the new symbols of educational endeavor. Each child, urban or not,

is made to fill a bottle at the kitchen faucet with the home water, to be brought to school and tested with silver nitrate for "sewage," for nothing so abstract as a chlorine ion must be mentioned. It is sometimes objected that, in cities, this is a waste of time, since all the samples would be the same. The objection seems to be very badly founded, for, in the hands of the high-school beginner, the identity of samples is no bar to the most exuberant diversity of results.

This movement is sometimes called the "grease-spot chemistry," on account of the central rôle played by making spots of oil on muslin and taking them out again with gasoline. The humble fruit-spot is less popular, on account of occasional difficulty in removing it, especially from colored fabrics.

I welcome the grease-spot chemistry, and perceive in it elements of great promise. True, many of the subjects taken up are somewhat trivial, and of such a nature that the student's mother could inform him more accurately and expeditiously than can his text-book. True, I should dislike to trust myself, even in a ferry-boat, upon water which had no better sanitary status than the favorable report of a high-school senior. But as an unconscious reaction against a method which introduces generalizations before there is anything to generalize, the movement is a favorable symptom. Progress is usually the net result of just such vibrations, first to one side of the position of equilibrium, then to the other.

That the "new chemistry" is only dimly aware of its own aims and purposes can be gleaned from a study of the books written to guide it, of which there are several now on the market. One would expect them to discard the analytical method, and it is not a little surprising to find them, instead, carrying it to a degree which may fairly be called a *reductio ad absurdum*. The formal logical abstractions of the science are hurled at the student *en bloc* in the first hundred pages, which form a kind of Liebig's Beef Extract of chemical science. Technology occupies the remainder, and the connection between the two portions is of the loosest description.

2. *The Principles Which Form the Basis of the Present Paper.*

But we have run amuck long enough. It is time to become constructive. Let me state, merely because I need them, two maxims which, taken together, make up a thumb-nail pedagogy.

There is nothing novel about them. They are not slogans which originated yesterday and will be forgotten to-morrow, nor are they bits of euphemistic, alliterative cant. One, at least, was known to the ancients, and very likely the other also—at all events it is equally unquestionable.

(*a*) "Teaching should proceed from the familiar to the unfamiliar, from the easy to the difficult, from the concrete to the abstract." Does the maxim seem unnecessarily wordy? If so, chop it off right behind the ears after "unfamiliar," and you will not mangle the sense seriously. However, the familiar is not always the easy, if the treatment is to be at all exhaustive. The boiling of an egg is familiar enough, yet Emil Fischer, in spite of his marvellous work on the chemistry of the albumins, would refuse to explain exactly what happens.

The last phrase, "from the concrete to the abstract," adds something to the meaning. The concrete is that which is immediately apprehended without effort, and without any chain of reasoning connecting it with anything else. The words "man," "knife," "book" are typical concrete terms. The abstract, on the other hand, is that which is more or less slowly *comprehended* by a train of reflective thought, based on its relation to other things which are more familiar. Atoms, molecules, oxygen, solution are abstract to the beginner, while a term like potassium chlorate is neither concrete nor abstract, but mere jargon, wholly incomprehensible, since by no reflective process can he acquire a conception of its meaning.

Evidently things which are abstract and strange to one person may be concrete and familiar to another, or even to the same person at a later stage in his career. To one who has looked, in the ultra-microscope, at the particles of a colloidal solution being driven hither and thither by the molecular impacts, the conception of molecule becomes concrete. Even the electron acquires a measure of concreteness when it is fired into the ionization chamber of an electroscope, and manifests its presence there by the kick of the projection on the screen. It is plain, also, that the concrete is at first largely the useful—which is sure to be familiar—and that a great part of education consists in the graduated logical conversion of the abstract into the concrete.

And now let us glance at school chemistry in the light of this ancient principle. What are we to think of our introductory

chapter, with its rapid definition of one abstraction after another "to clear the ground?" What of the attempt to explain processes which are themselves abstract, at this stage, by the aid of substances which are not even names to the student, since he cannot pronounce the terms used to designate them, and has not the dimmest glimmering of their meaning? What will it profit the beginner to elucidate the nature of chemical combination to him through the union of aluminum sulphate and potassium sulphate in solution to form hydrous potassium aluminum sulphate? Yet this is an actual instance. What advantage is anticipated from restricting the early part of the work to invisible gases, which the beginner cannot weigh nor handle, and which are themselves abstractions to him? Air is the most familiar gaseous substance, and yet, in the history of human development, it is only the other day, so to speak, that man learned that the air has weight, and it required the intellect of a Galileo to take this forward step.

I can perceive no escape from this dilemma. Either the maxim we have taken for granted is incorrect—in which case education falls into chaos, and there is no such thing as common sense—or else the problem of the most efficient plan of presenting chemistry to the American beginner remains to be solved. We are far ahead of the other nations in the universality of our laboratory work, and in our equipment for it, but far behind some of them in the order of topics and the method of presentation.

It is for this reason that we should extend the hand of fellowship to the devotees of the grease-spot. They are right in their contention that the concrete should play an important part. They are altogether at sea, however, in their desire to occupy the student entirely with the useful, the "practical," with *facts,* in other words, and to banish abstract thinking. Facts which lead nowhere, which are not concerned in any way with generalizations or with the solution of problems, are nearly worthless. Facts cannot be separated from thinking, nor thinking from facts. The jingling stock-phrase "sanitation, not meditation" exemplifies the futility of the attempt, for sanitation without profound meditation is impossible.

(*b*) Knowledge which has been gained with some purpose in view—whether to verify a hypothesis or to carry out successfully some practical operation, seems to make little difference—appears to form an organic part of the mind. It is obstinately retained

and is fairly sure to be instantly available when wanted. On the other hand, information acquired by a mere act of memory is a kind of external mental deposit, for it is relatively evanescent, and it has, moreover, a capricious habit of concealing itself temporarily when most needed.

Let me make a personal confession of a striking instance. For several years I have occupied myself, at different times, with attempting to devise an experiment whereby my students might convert a fixed weight of copper wire into cupric oxide, right in a small porcelain crucible. The idea was attractive, for the change in properties is unmistakable (a most important point in an experiment for beginners), the increase in weight is almost exactly one-fourth of the weight of the copper, and the atomic weight of copper can be neatly calculated directly in terms of the oxygen standard. *Reduced* copper, made by heating the oxide in hydrogen, can easily be oxidized quantitatively in the air, but direct oxidation, even of fine wire, gives an incomplete conversion, and, though the wire can be nicely changed to nitrate in the crucible, the ignition of the nitrate to oxide cannot be effected without loss. Many plans were tried, such as filling the crucible with asbestos fibre, sprinkling the cupric nitrate with oxalic acid, and so on, but none of them worked. Finally, I hit upon the notion of mixing the cupric nitrate, obtained by dissolving a weighed portion of wire in nitric acid, with powdered ammonium carbonate, hoping that the basic cupric carbonate might pass smoothly into cupric oxide on heating. So far as I can recall, it was about the time that the lid of the crucible struck the ceiling that the fact occurred to me that the double nitrate of copper and ammonium had been practically employed in blasting. This bit of information, picked up from Dr. Munro's excellent report on chemical manufactures in the census of 1900, had been in my possession about twelve years at the time, but it was a mere isolated fact, acquired by an effort of memory, kept in cold storage, and quite unavailable when needed. Thus did I relearn it, in connection with a particular problem, and I shall never forget it again.

Was du ererbt von deinen Vätern hast,
Erwirb es um es zu besitzen.
Was man nicht nützt ist eine schwere Last,
Nur was der Augenblick erschafft, das kann er nützen.

This antithesis, between erudition or stored-up learning and wisdom, which is knowledge put to work for the good of its possessor, is of first-rate importance. How can we arrange things in such a way as to cause the largest possible fraction of the learning acquired by the student to take the form of available knowledge, and not of mere erudition in cold—and probably not aseptic—storage?

Let us consider one of the most important of all chemical topics, the study of the atmosphere, which properly belongs in the very early part of the course. According to the analytic plan, which is essentially the current plan, the atmosphere is analyzed by the teacher or the text into its constituents, the properties of ogygen are communicated, then those of nitrogen, then those of the minor components, finally the nature of the air is inferred from its composition. A slightly better order is to make a brief reference to the biological and physiographical importance of the atmosphere at the start, and then to proceed with the dogmatic treatment.

The methodological or inductive way of attacking this subject, which was worked out by the great reformers of chemical teaching, Arendt and Wilbrand, and put into its present form chiefly by Ohmann, starts with the rusting of the metals. It is shown that the rusting is much accelerated by heat, which, however, is not able alone to produce it, since a folded piece of sheet copper, when heated, remains bright on the inside, although the outside becomes badly rusted. The necessity of air can be further brought out by a reference to the tungsten lamps of the laboratory, in which a metal which rusts at once, when heated in the air, is maintained in a vacuum at a dazzling white heat for long periods, without being affected.

The student heats a weighed piece of sheet copper and finds, on reweighing, that there has been an increase. This at once suggests the addition of something from the air. It will be noted that we are following the line of thought which brought about the downfall of Phlogiston and the discovery of oxygen.

Does the air, then, disappear when a metal rusts in it? Iron powder, hanging from a magnet, is burned in a confined volume of air over water. A portion of the air disappears, and the residual gas no longer supports the combustion of a taper.

What about other metals? How much of the air is absorbed

when rusting occurs? A litre of air is passed slowly through a combustion tube containing hot copper, most conveniently by pouring a litre of water into a flask so arranged that the air will be forced over the copper as it is expelled. This is a demonstration experiment, unsuited for laboratory treatment. About eight hundred cubic centimetres of unabsorbed gas collect over water in a graduated cylinder. This gas can now be named, and those of its properties which are not readily accessible can be communicated.

Oxygen, as the gas which disappears in the last two experiments, can also be named at this stage. The fact that it forms a series of compounds with the metals has been exemplified, and the student's knowledge can be enlarged by simple laboratory work dealing with the heating of iron, tin, lead, zinc, and magnesium. The term *oxide* can logically be employed at this time, though many prefer to reserve it until ogygen itself can be prepared. How is this to be accomplished?

Platinum is heated by the student, and silver and gold by the teacher. The lack of action contrasts strongly with the behavior of the base materials, and calls for explanation. The permanence of the lustre of these three metals is recalled, and the connection of this unalterability in the air with their uses pointed out. A little silver oxide is heated by the teacher, and the cause of the inactivity of this class of metals becomes plain. Evidently the oxides of these metals are decomposed by heat, so that, when once obtained, they form a potential source of oxygen.

Mercuric oxide is now introduced, as the oxide of a metal intermediate between the noble and the base metals, and much cheaper than the former. The student heats, in a hard glass tube, a quantity of mercuric oxide so small that it is completely consumed. This apparently trivial point is important, not only for proper economy in the use of such an expensive material, but also on account of the fact that otherwise he will not appreciate that the formation of the gas and the metallic liquid is accompanied by the disappearance of the red powder. This, by the way, forms a good place to call the attention of the students, for the *n*th time, to the fact that their inevitable tendency to take too much of everything is not only wasteful, but that it frequently defeats the whole object of the experiment. Chemical supply houses should put a phonograph on the market which would automatically repeat this

admonition at intervals of five minutes during all laboratory periods.

The student's knowledge of oxygen can now be enlarged with the aid of a cylinder of the compressed gas, the present method of preparing which, from liquid air, can be briefly indicated, to be explained more fully when the liquefaction of gases is discussed.

The potassium chlorate experiment should be deferred. At this time he is without a clue to the mechanism of the production of the gas. The effort to explain the purpose of the manganese dioxide deepens the mystery. Later, the exercise forms a valuable review of combustion, as well as a typical instance of catalysis.

It is, of course, understood that the treatment broadens later to include combustion, flame, the oxides of carbon, and so on. We are now restricting ourselves to the chemical composition of the air. The close of this special topic is formed by a discussion of the work of Priestley, Scheele, Rutherford, Lavoisier, Rayleigh, and Ramsay, in which the parallelism between the path followed by the course and the historical development is clearly brought out. The teacher who is in search of the best method of presenting a topic to beginners may, with great profit, study the history of the subject. It is surprising how often this indicates the best avenue of approach, though there are striking exceptions. The fact that beginners are always much interested in the historical side is also worthy of note.

Preceding this inductive-deductive study of the air, there is, of course, an opportunity for the student to acquire, by simple experimentation, some knowledge of the nature of chemical combination. It would be difficult to devise a worse experiment for this purpose than the one usually recommended—the heating of a mixture of iron filings and sulphur. The change in appearance after heating is slight, the iron sulphide is invariably magnetic, and almost any proportions in the mixture will apparently yield the same result. The usual direction to treat the mass with hydrochloric acid before and after heating adds to the confusion, for the beginner can supply no interpretation of the behavior of his olfactory nerve. Moreover, the hydrogen obtained by treating the unheated substance with acid contains appreciable hydrogen sulphide and has a most unsavory odor. The important features of a chemical process are completely lost in this exercise, which,

as questioning will show, always fails to fulfil its intended purpose.

One brilliant student of the problems of elementary teaching, Karl Scheid, employs calcite for this preliminary work, while another, Otto Ohmann, makes use of some simple experiments on the formation of the sulphides of the metals, especially of copper. The advantages are all with Ohmann's procedure. Scheid's experiments on the heating of calcite to lime, on the slaking of lime, on the dehydration of slaked lime, and so on, suffer from the difficulty that exact results are almost impossible under high-school conditions. Another objectionable feature is that all three of the substances just mentioned are so similar in appearance that, barring accurate quantitative results, the evidence that a change has occurred is indecisive. The primary thing to remember, in planning this introductory work, is that we have no special sense for the recognition of chemical processes. We apprehend them only by the associated physical changes. Scheid forgets this fundamental principle. To let the student convert one white powder into another, indistinguishable from the first, has no effect worth mentioning on the development of his ideas, even if a change in weight is established. Let us be just to Scheid, however, by adding that his course is rich in suggestions of the utmost value, and that no teacher who gives it careful study can fail to derive great benefit.

Ohmann's experiment on the *synthesis of cuprous sulphide* deserves the attentive consideration of the teacher who is in search of a decisive instance of chemical change for his classes. The details are given in my "Laboratory Manual," page 11. The original is in the *Zeitschrift für den physikalischen und chemischen Unterricht*, about five years back. Two of the strong points which it shares with the other similar experiments have been referred to. The results are sufficiently accurate and the change is unmistakable. A third is the fact that the change in weight happens to be almost exactly one-fourth of the weight of the copper—which presents the essence of the matter devoid of all arithmetical complications. A horn-pan hand balance is quite sufficient for the weighing. It is well to clinch matters with a more exact synthesis with No. 30 copper wire and sulphur in a porcelain crucible (*Ibid.*, p. 13).

Let us return to our general principle (*b*). Work of this

kind needs more planning than a course in which everything is communicated, but it is easier in the execution, on account of the whole-hearted participation of the students. Thomas Carlyle remarks somewhere that to sit like a passive bucket, and be pumped into, can, in the long run, be exhilarating to no creature. And, unfortunately, the mental bucket is far more leaky than the physical one.

We can now state the general plan of such a course. Since the leading idea is clearly set forth by Dewey, and since the application to class-room instruction in physics has been worked out by Mann, we can be brief. A problem based on some familiar occurrence is presented. Vagueness is eliminated and the problem defined by preliminary experiments. Thus we find, in our typical case, that other common metals behave like copper, that there is an increase in weight, that the color of the solid formed is non-essential, and that the noble metals are unaffected. A *solution*, a hypothesis suggests itself. This hypothesis involves certain consequences which can be tested by new experiments. *If* the darkening of the copper is *really* due to the action of the air, and not merely to heat, a folded piece of copper will not be affected on the inside, where the air has no access. These tests either quash the hypothesis for good and all, or establish it as a fact which can function as one element of a new problem. True, the air is the cause of the loss of lustre of copper and other metals when heated, but is all or only a part of the air concerned in this? If the latter, air confined over water will only partly disappear when a metal is heated in it. Just how much of the air is taken up by a hot metal? Does the air which remains differ from common air? How does it act towards a burning candle? Is there any similarity between *combustion* and rusting?

This procedure—the sensing of a problem, the limitation and definition of the problem by experiments, the inductive formation of a hypothesis, the deductive treatment of the hypothesis to obtain its consequences, and the testing of the consequences by further experiments—is simply the *scientific method*, the most tremendous weapon in the intellectual armory of mankind. When the mind works in this way it arrives at truth, or, in the absence of sufficient data, at suspended judgment. Other modes of operation show their inherent unsoundness by yielding a chaos of divergent opinions. "By their fruits ye shall know them."

Unfortunately those who understand the method, and are able to use it, form a vanishing minority—hence the deplorable state of the world at the present moment, for when both parties to a controversy employ the scientific method, an irreconcilable difference of opinion is unthinkable. Polemics, based on faulty observations or diverse interpretations, may occur, but shortly the two will either arrive at the same conclusion, or will together admit the impossibility of any valid conclusion and begin once more to accumulate data. A student who had learned the scientific method and nothing else in his four years of high-school life would have spent his time to better advantage and would be better fitted for citizenship than if he had been crammed with subject-matter to the very ears. If he desired to spend his time in that agreeable manner, he could almost at once learn to remove grease-spots much better than the tailor's apprentice, and in five minutes he could find out more about "mother's oven" than the practical gas-fitter will ever know. And, above and beyond all trivial matters, he would possess a talisman far more wonderful and more precious than Aladdin's lamp, which would confer upon him the power to distinguish science from pseudo-science, assertion from proof, truth from falsehood.

No wonder that the historical development so often points out the best order of topics! To teach according to the historical sequence, to give the method of science along with its subject-matter, to throw the work into the form of problems significant to the student, these are little more than statements of the same principle in different words.

3. *Limitations, in Actual Work, of the Two Principles Just Discussed.*

I recall a fellow-student in high school who, during recess, offered a criticism of the teaching of geometry which ran somewhat as follows:

"If these theorems are any good, we ought to learn as many of them as possible in the time we have for the subject. Now we could learn ten times as many if we did not bother with the demonstrations. The demonstrations are useless anyhow, for we are all willing to believe the theorems without proof, and we ought simply to learn them by heart."

The fallacy in the recommendation of this young educational reformer is, of course, that drawing inferences is the main busi-

ness of life, the one thing in which we are all constantly engaged, but his proposal embodies an effective caricature of the present plan of presenting chemistry by trying to nurture the mind of the beginner on an artificial product composed of the results of the science, with little reference to the method by which they are obtained. School geometry is real geometry, as far as it goes, and school Latin real Latin, but school science, conducted on this plan, is not real science at all, but a mere popular survey, from which the essential scientific spirit is absent. This is the main reason that the sciences have not accomplished what was expected of them when they acquired an assured place in the curriculum. Our science is the very foundation of agriculture—which is little more than a branch of applied chemistry—yet we are confronted with the fact that, in great agricultural states, the number of students taking Latin is many times the number in chemical courses, seven times as many throughout the country. For a fair parallel, imagine a commercial school in which the pupils deserted the rooms devoted to stenography and typewriting, and crowded to suffocation lectures on the geometry of the fourth dimension, or the metrical values of Sanscrit verse.

The future is sure to change this state of things. When tradition and inertia have been overcome, and the schools begin to render their service to the community with maximum efficiency, the subjects which stand in intimate relation to life and its needs will dominate the curriculum, and the ballast which we have inherited from a former age will occupy a subordinate position, or even disappear.

We have just examined two principles with which our teaching must, sooner or later, be brought into agreement. Let us now attempt to forecast the limitations which will be encountered when we attempt to apply these generalizations in actual teaching in the American high school.

(*a*) The plan just stated, and worked out in a typical study of the atmosphere, must not be regarded as a rigid Procrustean scheme, into which every topic must, willy-nilly, be forced, but as an ideal, to be approached quite closely in some cases, and to be departed from widely in others. The sulphides, air, and water can be handled in this way with admirable results. The next topic which naturally suggests itself, that of common salt, offers more difficulty, on account of the impossibility of extracting the

sodium from sodium chloride in the laboratory, but the method can still be used with great profit. With fluorine and its compounds, or with the hydrocarbons, the plan would be so unsuitable that sane common sense at once dismisses it as impracticable. Here we must resort to communication, vitalized by reference to familiar phenomena, by the mineral collection, and by significant laboratory and demonstration experiments. We shall see, in a moment, that, in all topics, the treatment recommended must, at some stage or other, retire and give place to systematic communication.

(*b*) "Rediscovery" is not the object of the work, and is, in general, impossible under high-school conditions. We are all acquainted with the futile and dangerous tomfoolery of the pupil who starts to investigate on his own account. Leadership there must be, and the dogmatic analytical method at its worst is far better than the anarchy of haphazard experimentation. A class simply turned loose in the laboratory would accomplish nothing, and would require the constant services of a well-equipped fire department, a good hospital, and perhaps an undertaker or two. The student who could rediscover chemical science in a year's course of five periods or so a week would be an intellectual giant beside whom men like Lavoisier and Faraday are mere insects in the dust. The teacher would be so cast down by the inevitable comparison between his own modest acquisitions and the marvels achieved by his classes that he would apply to an osteopath for treatment whenever he suffered from headache.

I insist on this elementary point on account of the exaggerated statements which are published from time to time by critics without experience in high-school teaching. Claims that the student should himself select the problem, devise the method of attack, work out in tributary researches any general principles that may be needed, and construct the apparatus required are sheer nonsense, which serves only to delay needed reforms and to provoke reactions to mechanical methods.

Take the particularly simple case of Boyle's law. The lad who was provided with a stand, meter stick, glass tubing, mercury, and *no guidance* would have about the same chance of arriving at the law as a font of type would have, when placed in a bag and shaken, of setting up the text of "The Tales of Baron Münchausen." *With* guidance, which tells him exactly what to

do, and, to all intents and purposes, what he is to observe, he is able to understand the train of thought which Boyle pursued, and to verify the law up to a pressure of about two atmospheres. Boyle himself went no further, though he did experiment with air at pressures of less than one atmosphere. This places the student in a very different position from that which he would have occupied if he had merely chanted a formula that the volume varies inversely as the pressure, but he has not *rediscovered* any general law about the conduct of gases. He has followed the track blazed for him by Boyle, and he has worked with but one gas and over a very small range of pressures. Communication must now be resorted to, if he is to know anything about higher and lower pressures, and about the behavior of different gases. Similar statements hold good with regard to the expansion of gases by heat.

The student's personal knowledge, even supplemented by the laboratory, is narrow, and must be enlarged by communication on every topic. But there is all the difference in the world between communication to the learner who has worked through concrete similar examples, and communication to the learner who has not, and who must try to find a foothold on the unsubstantial foundation of mere verbiage.

The law of constant proportions, simple as it is, is not always easily comprehended from mere description. However, a single instance—for which I employ the solution of a weighed portion of zinc in hydrochloric acid, comparing the weights of zinc chloride obtained by different students using multiple weights of zinc—suffices to render it perfectly familiar, and its application to innumerable other cases presents no difficulties.

The idea of atomic weights does not become concrete so readily. Explanation is of hardly any service here—problems are better—but I have not found it possible to give a concrete working knowledge of this indispensable idea by problems alone. The tendency to confuse atomic weight with *density* is surprisingly difficult to eradicate. To let the student determine two or three atomic weights for himself at once annihilates his perplexities. The atomic weights of copper, tin, and magnesium can be determined with sufficient accuracy in about an hour, with only the apparatus at hand in every laboratory.

In this procedure of generalizing from a few instances only,

there is nothing unscientific, for the actual investigator does exactly the same thing. No reasearch worker tests all included cases before forming his generalization. He may often set up a working hypothesis on a basis of one instance only.

4. *A Workable Scheme.*

It is time for us to profit by the experience of some of the European nations which, while behind us in laboratory facilities, are in advance of us in the arrangement of the work. The course should be divided into two distinct phases, each with its own aims and purposes.

I. THE FIRST PHASE.

The object of the first phase of the chemical work is the orderly development of the general indispensable principles of the science. Method should be supreme, chemical system and classification should be allowed no weight whatever, and the condition of the mind of the student should not be forgotten for a moment. Each topic should be started with something concrete and significant to him, or with something which can at once be rendered concrete in the laboratory, or by the aid of the mineral collection. A typical example of this kind of treatment has been sketched in connection with the atmosphere. Everything except scientific accuracy should be subordinated to the observance of the two principles already discussed. As subjects for this first course, the following naturally suggest themselves:

(*a*) A study of familiar elements which occur native, especially sulphur, carbon, and the common metals. This should include the mineral sulphides and the preparation of the metallic sulphides, and out of it should emerge the essential characteristics of a chemical process.

(*b*) A study of the atmosphere, somewhat as indicated above, which should be extended to cover combustion, carbon dioxide, etc. If not relegated to physics, the general properties of gases and the kinetic theory of matter—which is now a fact—can form the conclusion.

(*c*) Water and hydrogen, the latter being obtained not from acids, but from the water by means of zinc dust. A natural conclusion is formed by the action of hydrogen upon oxides and of carbon upon oxides, with the related metallurgical processes.

(*d*) Common salt, sodium, and chlorine. Hydrogen chloride in detail and briefer treatment of the important compounds of

chlorine with the elements already studied. The first phase can here be concluded with a concise, systematic survey of the ground thus far covered.

Symbols and formulæ can be introduced in (*b*) in connection with the oxides of the metals, the sulphides being also pressed into service. The idea of molecular weight can be adumbrated in (*c*) and fully set forth in (*d*). The essential facts of solution can be given at the beginning of (*d*) in connection with the physiographical and industrial treatment of salt, but the application of the idea of molecular weight to solutions, and the treatment of ionization and electrolysis, are best deferred.

II. THE SECOND PHASE.

In the second phase, also, the two great educational principles which dominate the whole should receive constant attention, but, since the student now has a considerable chemical experience, and quite a large store of familiar instances with which to assimilate his new acquisitions, the movement can be freer and more systematic, with somewhat less emphasis on methodological considerations. Space is lacking to enumerate the subject-matter, which includes the chemical domain which every child should know. I must confine myself simply to making a few suggestions.

(*a*) If time is available, the brief summary indicated as a suitable conclusion to the first phase can be omitted, and replaced, at the beginning of the second phase, by a more detailed and systematic study of some of the more important elements which have already been encountered. This would be the place, for example, for the production of hydrogen from acids and of oxygen from potassium chlorate, for ozone and hydrogen peroxide, and for further details regarding the chlorine compounds.

(*b*) Consider a sequence of topics like the following: lead, lead oxide, lead sulphide, lead chloride, lead sulphate, lead nitrate, lead carbonate, etc. The only connection is that all the seven materials contain lead. In the study of such a series there is an incoherence, a jerky mental movement, due to the inconsecutiveness of the arrangement, to the almost complete lack of congruity among the topics. In a hand-book such a grouping is satisfactory, because it makes it easy to find things. But there is no good reason for copying the arrangement in the presentation of a science to the beginner. Familiarity, logical order, and

congruity are the only considerations which are relevant and to which any weight should be allowed. Lead sulphide, as an important mineral which can be cheaply purchased in almost pure condition for laboratory work, finds its natural place among the sulphur compounds, near the beginning of the first phase. Lead oxide can be logically handled in connection with the action of air on the metals.

Where some systematic classification must be followed, it is usually better to group salts according to the acid radical, rather than according to the metal, for the purposes of elementary study. Thus the nitrates form a fairly coherent topic, closely connected genetically with nitric acid and with the oxides of nitrogen. The solubility relations of the nitrates can be discussed in the light of the important case of potassium and sodium nitrates, and the fixation of nitrogen forms a suitable conclusion. All this cohesion is sacrificed if the nitrates are merely scattered among the metals.

(*c*) I have elsewhere expressed the opinion that the actual value of technology to the student is greatly exaggerated in some quarters. He will more frequently have opportunity to apply the purely scientific aspects of the subject. Moreover, through no fault of the teacher, the technology of the high-school course is apt to diverge quite widely from the actual conditions in practice, which change so rapidly that the processes of the elementary text are often obsolete before the book appears in print. All of us are acquainted with the constant necessity of correcting the technology of the book we happen to be using.

As an illustration of the uncertainty of technological information, consider one point in a rather stable process—the manufacture of ordinary soda glass. In common, I suppose, with most teachers, I had been in the habit of dismissing the sodium aspect of this matter with the statement that the carbonate had been used but was largely displaced by the sulphate, which furnished the sodium more cheaply. Two years ago I learned, in conversation with a large glass manufacturer, that Chile saltpetre had almost entirely displaced the sulphate, the oxidizing action being regarded as an advantage. At present, while the imports of Chile saltpetre into the United States have not increased to any great extent, the demand for it for the nitric acid manufacture is quite unprecedented, and the glass-makers seem— to judge

from that uncertain criterion, newspaper reports—to be forced back to the use of soda ash.

The sane thing seems to be to add interest by the aid of technology, to keep the applications of chemistry to human needs before the students, but to avoid over-emphasis. Special attention should be paid to those cases in which a technical process exemplifies and clears up an important general principle. An illustration is the connection of catalysis with the manufacture of sulphuric acid, both in the lead chambers and by the contact process.

(*d*) In all these recommendations there is nothing revolutionary and nothing radically new. In Germany the abandonment of the dogmatic analytical procedure began with Arendt (1862) and Wilbrand (1870), and has been complete for a generation. In England the same movement has progressed under the leadership of Perkin and Armstrong. Since the basic idea is to proceed logically from the concrete to the abstract—and, where possible, to return to the concrete at the end of the train of thought to clinch the principle by an application significant to the student—the plan leads to an unusual attention to household matters, familiar phenomena, every-day affairs. Thus far are we in accord with those who would have us make our teaching more practical. But we wish to interpret the word not with the myopic vision of the half-educated man, who despises everything which he cannot understand, but with the wide and imaginative outlook of the man who knows that the disinterested research of to-day is the factory commonplace of to-morrow. The commercial history of the world for the last fifty years points the moral that the nation which fails to grasp the value of science, and especially of chemical science, is moving to disaster. America should learn this lesson *now*, and not through an industrial catastrophe hereafter.

The Microscopic Structure of Semipermeable Membranes and the Part Played by Surface Forces in Osmosis. F. TINKER. (*Proceedings of the Royal Society,* Series A, vol. 92, No. A641, May 6, 1916.)—Hitherto very few experimental observations have been made to arrive at some of the fundamental facts associated with the mechanism of osmosis. Raoult, Flusin, Kahlenberg, and a few others have shown, however, that certain membranes, such as parchment, gelatine, and rubber, absorb the liquids to which they are permeable, and are impermeable to liquids which they do not absorb;

Bigelow and Bartell have shown that, under certain conditions, the rate of flow of water through a membrane such as copper ferrocyanide obeys Poiseuille's law for the rate of flow through capillary tubes; while Beutner, Donnan, and others have proved that certain precipitation membranes can act as electrodes, reversible with respect to various ions. The further questions which are dealt with in the present communication are experimental ones, such as: What is the size of the colloidal particles of which a semipermeable membrane is composed, and how is the membrane built up from those particles? To what extent does a membrane show the properties of the gelatinous precipitates or gels as ordinarily prepared by bulk precipitation? How is the structure of the membrane altered by variations in the method of its formation, the nature of the solutions bathing it, and the treatment to which it is subjected? and what is the size of its pores, the extent to which they are under the control of the surface forces and therefore of absorption phenomena also?

(1) The common precipitation semipermeable membranes are composed of small precipitate particles, ranging from 0.1μ to 1.0μ, these particles being packed closely together. Each of these precipitate particles is, however, not simple in structure, but is itself an aggregate formed by the flocculation of semimicroscopic colloidal particles. The particles composing the membrane are smallest in the case of copper ferrocyanide and Prussian blue. (2) Precipitation membranes show most of the properties of gels, as ordinarily prepared, both in their method of formation and in the changes they undergo in various solutions. Like ordinary gels, they are possessed of great tensile strength, which varies in membranes of various kinds. Their stability in the colloidal condition also varies greatly. But, although they show the physical properties of gels, they have not the same mechanical structure, the membrane being much more closely knit together than the gel proper. (3) The pores in a copper ferrocyanide membrane range from 8 to $60\mu\mu$ in diameter, the average diameter being from 15 to $20\mu\mu$. The pore size is too great for the membrane to act osmotically by exerting a selective blocking action. (4) The order of a series of membranes in pore size is the same as that of their efficiency as semipermeable membranes. Copper ferrocyanide and Prussian blue are the most efficient membranes, and they have also the smallest pores. (5) There is also very close connection between the osmotic properties of a membrane and the extent to which the membrane capillaries are under the control of surface forces. Osmotic effects are probably the result of selective absorption phenomena occurring at the surface of the membrane and in the capillaries, the membrane being relatively impermeable to solutes which are negatively absorbed, but permeable to solutes which are positively absorbed.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

SUMMARY OF EXPERIMENTS ON THE SILVER VOLTAMETER AT THE BUREAU OF STANDARDS AND PROPOSED SPECIFICATIONS.[1]

By E. B. Rosa and G. W. Vinal.

THE investigation of the silver voltameter at this Bureau was first begun by the late Dr. K. E. Guthe, in 1904. His results were published in two papers about a year later. In 1907 the work was again taken up by Dr. N. E. Dorsey in coöperation with the present authors, but the results obtained at this time did not confirm the experiments of the National Physical Laboratory, which were then newly published, and new difficulties arose which were not understood. These experiments were not published. In the following year the work was resumed and preparations for a very thorough study of the silver voltameter were made. The voltameter received added importance when the ampère was adopted by the London Electrical Congress as the second fundamental electrical unit, so that the investigations which the present authors began in the summer of 1908 have passed beyond the original plans in scope and duration. This has also been due, in large measure, to the numerous and intricate sources of error which were discovered in the course of the work, all of which required painstaking investigation.

Other experimenters have coöperated with us during the course of the work. These were Dr. A. S. McDaniel, Prof. S. J. Bates, Prof. G. A. Hulett, and Mr. Wm. M. Bovard. The results of the investigations have been published in a series of eight papers. The present paper contains a summary of these eight papers, and the Bureau's proposed specifications for the voltameter. No adequate specifications have been adopted since the London Conference of 1908, and it is hoped that the carefully drawn specifications which the Bureau presents in the complete paper may be adopted as a whole or in part when it is possible to

* Communicated by the Director.

[1] Scientific Paper No. 285.

reach an international agreement. For the present, the specifications are available for the guidance of such investigators as wish to use the silver voltameter.

A few of the principal results of the voltameter investigations which are summarized in the present paper are the following:

1. The effect of filter-paper on silver nitrate solutions, whether the paper is used in the voltameter itself, as has been commonly done, or whether it is used in the preparation of the silver nitrate solution, was shown to be serious and to result in the formation of colloidal silver. This effect of the filter-paper is due to the formation of reducing agents from the oxycellulose of the paper itself, and is not due to impurities.

2. The appearance of the deposit is altered by the presence of impurities in the solutions (such as those resulting from filter-paper). Pure solutions give crystalline deposits of very pure silver, but colloids, if present, break up the crystals and produce striated deposits which are too heavy to accurately represent the electricity which passed through the voltameter.

3. Many forms of voltameter have been compared. The Bureau has found as the most satisfactory the porous cup voltameter, and the new form devised by Mr. F. E. Smith, of the National Physical Laboratory.

4. The Bureau has devised means of preparing pure silver nitrate and suitable tests for it, so that the electrolyte may be of a uniformly high state of purity. These tests are for acidity and for reducing agents. The Bureau has also found that the agreement of large and small sizes of voltameters, when used simultaneously, is a valuable test of purity, since impure solutions (except for acid) invariably give heavier deposits in the large-size voltameters. This phenomenon we have called the volume effect.

5. The temperature coefficient of the voltameter is found to be zero.

6. Tests on the purity of the silver deposits show that when made from pure electrolyte the impurities included with the silver crystals represent only 0.004 per cent. of the weight of the deposit, on the average.

7. The absolute electrochemical equivalent of silver was found to be 1.11800 mg. per coulomb, and the voltage of the Weston normal cell was found to be 1.01827 volts at 20° C.

8. Comparisons with the iodine voltameter were made and the ratio of silver deposited to the iodine deposited by the same current was found to be 0.85017, which, corrected for the inclusions in the silver deposits, gives 0.85013. The electrochemical equivalent of iodine in absolute measure was computed to be 1.31507 mg. per coulomb. The value for the faraday on the basis of the absolute electrochemical equivalent of silver and iodine and their atomic weights is as follows:

On the silver basis (Ag = 107.88)	96,494
On the iodine basis (I = 126.92)	96,512
Mean	96,503

The best round value which can be assigned to this constant appears to be 96,500 coulombs.

A brief history of the specifications for the voltameter which have been used in the past is given, followed by the Bureau's proposed specifications. An appendix contains an extensive bibliography of the silver voltameter.

CALCULATION OF PLANCK'S CONSTANT C_2.*

By J. H. Dellinger.

THIS constant, which is of great importance in high-temperature measurements and in atomic theory, has heretofore been obtained from radiation data by processes involving the use of a graph. It may be calculated directly and very simply from any two observations. A solution of Planck's equation for c_2 in terms of the ratio of energies at any two wave-lengths and temperatures is readily obtained, c_2 appearing in a correction term in the solution. The various relations which have been used for obtaining c_2 from radiation data are deducible as special cases.

The equation for two observations of wave-length at constant temperature is of special interest: the following approximate expression is sufficiently exact for most cases:

$$c_2 = \frac{\lambda_1 \lambda_2 \theta}{\lambda_2 - \lambda_1}\left[\log \frac{J^2}{J^1} + 5 \log \frac{\lambda_2}{\lambda_1} - e^{\frac{c_2}{\lambda_2 \theta}}\right]$$

* Scientific Paper No. 287.

An approximate value of c_2 always suffices for the last term. This general method of solution is superior to the method of equal ordinates. No curve has to be drawn, and the calculations are not limited to particular pairs of points. The method is more powerful in determining whether an observed curve fits the Planck equation. In fact, curves which give normal values for c_2 by the method of equal ordinates were found to give very high values when calculations were made by this method for two points, both on the same side of the maximum.

Points on the Planck curve for which Wien's displacement law holds, in particular the maximum of the curve, have been considered as furnishing additional ways of determining c_2. Such methods are debarred by lack of accuracy, and, in fact, these special points may themselves be obtained most accurately and conveniently by the same process of using two observations which is used for obtaining c_2. Substantially the same simple equation suffices to determine c_2 and all the special points.

WHEATSTONE BRIDGES AND ACCESSORY APPARATUS FOR RESISTANCE THERMOMETRY.*

By E. F. Mueller.

A TYPE of Wheatstone bridge, suitable for use in resistance thermometry, has been developed, in which plugs or dial switches are used, and the circuits so arranged that the errors due to contact resistances are no greater than with the mercury contact bridges heretofore used. With a comparatively simple and inexpensive type of apparatus it has been possible to attain the high degree of precision and accuracy demanded in modern work with resistance thermometers.

A method of measuring potential terminal resistances by the Wheatstone bridge method is also given, and the necessary accessory apparatus for this purpose is described. The usefulness of the bridges may also be greatly increased by the use of an interchanger, by means of which a number of thermometers may be measured in rapid succession with a single bridge.

* Scientific Paper No. 288.

THE DAMPING OF WAVES AND OTHER DISTURBANCES IN MERCURY.*

By M. H. Stillman.

IN instruments involving the use of mercury the waves and other disturbances produced in the latter by the unsteadiness of the containing vessel are a frequent source of trouble. If a mass of mercury be subjected to a strong magnetic field, the direction of the field being approximately at right angles to the direction of motion of the mercury, this motion will be strongly damped. The motion of the mercury across the magnetic lines of force tends to produce an electric current, the reaction of which with these lines of force tends to stop the motion of the mercury.

It can be easily shown that the damping force on the mercury is given by the equation $F = K \sum \frac{lvB^2}{R}$ where l is the length of the element of mercury moving at right angles to the lines of force with the velocity v in a field of flux density B, and R is the resistance of the elementary circuit. K is a constant depending upon the units used.

The writer found that the substitution of a non-magnetic metallic container for a glass container greatly increased the magnitude of the damping. This was, of course, due to the decreasing of the resistance to the induced electric currents.

While this method is most effective in damping the larger oscillations and waves in a mass of mercury, since the magnitude of the damping is directly proportional to the velocity, it was found to be very effective in damping the small ripples, also.

It is suggested that this method might sometimes be used when it is desired to obtain accurate adjustments of mercury surfaces at sea and in other places where unsteadiness of the mercury container is unavoidable.

PROCEDURE IN MAKING ELECTROLYSIS SURVEYS.†

By Burton McCollum and G. H. Ahlborn.

THIS paper deals with the methods of procedure to be followed in examining underground pipe and cable systems and the return system of electric railways for the purpose of determining

* Scientific Paper No. 289.

† Technologic Paper No. 28.

the liability of the underground metallic structures to damage from stray electric currents from the electric railways. The paper describes the principal methods that have been successfully used by the engineers of the Bureau of Standards in work of this kind during the past five years.

The introduction sets forth the purpose of making electrolysis surveys, and outlines several classes of surveys that may be made according to the character of the information sought. The paper points out that by means of proper measurements it is possible to determine the extent and location of the areas in which the pipes and other structures are in danger, and the approximate degree of seriousness of the trouble. The cause of the damage in progress, whether due to stray currents or natural corrosion by soil, cinders, or organic matter, can generally be pointed out, and in case of electrolytic corrosion the source of the current can generally be definitely determined. The various factors tending to produce or aggravate electrolytic damage, such as local discontinuity or high resistance in the pipe systems, unusually low resistance soil; or, in the railway lines, poor rail-joints, infrequent cross-bonds, insufficient conductance in the negative return, improper use of such conductance, or too long feeding distances, may be determined, besides many questions of local importance. Attention is called to the fact that a large amount of preliminary data and information on the railway systems needs to be obtained prior to the making of electric measurements. These include:

1. The character of the service, whether city, suburban, or interurban. This will have a bearing on the schedule, momentary variation in load, and load factor.

2. Physical data on the railway systems, such as rail weights, types of bonds and joints used, and road-bed construction.

3. The practice of the railway company in regard to frequency of cross-bonding, bond maintenance, and bond testing.

4. Load curves are necessary for the interpretation of the data in order to reduce short-time readings to all-day or other average values. Where the load varies considerably in different sections of a power-house feeding area it may be necessary to get the load curves on different feeders as well as the total power-house load.

5. Where a survey is made with the ultimate purpose of correcting electrolysis conditions by applying some method of mitiga-

tion it will also be necessary to secure complete data on the magnitude and distribution of load, the generating and substation feeder systems, frequency of schedule, and probable future demands of traffic.

The electrical measurements required in electrolysis surveys are treated under three heads, namely: (1) Measurement of over-all potential drops between the points of lowest potential and outlying points on the railway system, potential gradient measurements in tracks and earth, and potential difference measurements between different systems of underground structures; (2) current measurements, including measurement of current in feeders and rails, measurement of current in pipes and lead cable sheaths, measurement of current leakage from buried metallic structures into the earth; (3) miscellaneous measurements, which include the location and testing of high-resistance joints in pipes, track testing, measurement of earth resistance, measurement of leakage resistance between railway tracks and earth, determination of the cause of corrosion, determination of the source of stray currents, location of concealed metallic connections, and examination of concrete structures.

There is also a section devoted to the discussion of the principles involved in the proper interpretation of the results of electrolysis test data, and the importance of having electrolysis surveys carried out under the supervision of an engineer thoroughly experienced in work of this nature is emphasized.

NOTES ON ELECTRIC RAILWAY TRACK LEAKAGE.*

By G. H. Ahlborn.

THE Bureau of Standards is issuing Technologic Paper No. 75, under the authorship of G. H. Ahlborn, entitled "Notes on Electric Railway Track Leakage." This report deals with data which were obtained as a part of the general investigation of electrolysis carried on by the Bureau of Standards. The object is to show the actual amount of leakage which may occur from street railway lines under operating conditions.

*Technologic Paper No. 75.

The physical characteristics of three suburban and interurban lines are given, and tests, conducted with the cars off the line and the concentrated load at the extreme end, described.

The first line is constructed with double tracks, the rails being imbedded in the street surface for most of the length, which is 5.5 miles. The road-bed of this line is quite well drained, and the elevation is between 200 and 300 feet.

The total leakage from this track, including that escaping from the terminal networks, is about 28 per cent. of the total current impressed, which was 300 ampères, or the leakage is 84 ampères. Calculations involving the distribution of leakage along the line show that the resistance of the track is increased 15 per cent. because of rail-joints, which is not excessive, since several isolated high-resistance joints increase the resistance, and the joints on the average are good. The average road-bed resistance for 1000 feet of single track is about 1.76 ohms.

The second line tested is single track, about 11 miles long, with the rails practically clear of ground. The elevation of this line is about 125 feet and the soil is chiefly sand and gravel, so that it drains readily. The leakage from this line amounted to 47 per cent., or, with the 150 ampères impressed, about 70 ampères. This is not as excessive as might seem in comparison with the first line, because the over-all potential drop required to force the current through this line was three times as great. However, the track was not in good condition, the joints increasing the resistance over that of the solid rail by 40 per cent. The resistance to ground was unusually high, being about 14.57 ohms for 1000 feet, or 2.75 ohms for one mile.

The third line was single track, about 6.5 miles long, with the rails generally clear of soil. However, the elevation was very low, being about 10 feet above sea level on the average, and the soil was impregnated with salt water from the surrounding marshes. The total current impressed was 205 ampères, and of this amount only 14 ampères remained on the track throughout its entire length, or the leakage was 93 per cent. Here, again, the over-all potential is high, being 87 volts, but the track was in very bad condition, the joints having increased the effective resistance to nearly 16 times what it would have been with continuous rails. For considerable distances one rail carried the entire current, and this rail had many high-resistance joints. The leakage resistance

was low, being 1.8 ohms for 1000 feet, or about 0.34 ohm for one mile.

This report emphasizes the importance of maintaining as high resistance to ground as is feasible, but especially of having a high standard of rail-bonding and cross-bonding on all lines.

THE PROPERTIES OF SOME EUROPEAN PLASTIC FIRE CLAYS.*

By A. V. Bleininger and H. G. Schuresht.

In this paper the properties of five well-known European plastic fire clays, largely used for glass pots, graphite crucibles, etc., were studied for the purpose of securing data, making possible a comparison with similar American clays. Such properties as the content of shrinkage and pore-water, drying shrinkage, fineness of grain, rate of drying, mechanical strength in the dry state, rate of vitrification, final softening temperature, and the chemical composition were determined. Tentative specifications are suggested, assisting in selecting American clays of similar properties. These include the following requirements: An extensive range of water content corresponding to a difference of about 40 per cent. between the minimum and maximum water contents, permitting of moulding the clay; an Atterberg factor of not less than 50 nor higher than 110; a ratio of shrinkage to pore-water of not more than 1 : 1.2; a total water content for normal consistency of between 30 to 45 per cent. in terms of the dry weight; a tensile strength in the plastic state close to 4 pounds per square inch; a disintegration time (in water) of not less than 50 minutes; a linear drying shrinkage of not less than 6.5 and more than 10 per cent. in terms of the dry length; a tensile strength of the clay, mixed with 50 per cent. of screened calcined clay, of not less than 150 pounds per square inch in the dried state; a modulus of rupture under the same conditions of not less than 350 pounds per square inch; a porosity of not more than 10 per cent. at 1150° C., and 5 per cent. at 1250° C., for crucible clays, constant porosity being maintained up to 1350° C. and 1400° C., respectively, for brass and steel melting, and a porosity of not

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* Technologic Paper.

more than 10 per cent. at 1350° C. for glass-pot clays; a softening point corresponding to standard cone No. 30 for crucible and, if possible, higher for glass refractories; a total content of fluxes (iron oxide, lime, magnesia, potash, and soda) of not more than 5 per cent. for crucible and 4 per cent. for glass-pot clays.

From the results obtained it was shown that these famous European clays do not differ radically from similar materials found in this country, but that the same results can be obtained with mixtures of known American clays. There is no lack of domestic clays suitable for the uses under consideration, and it is but a question of proper selection. The possibility is pointed out of securing with American raw materials results even superior to those obtained with the foreign clays by mixtures of two distinct types, the open and dense burning clays. The imported clays show certain faults which may be eliminated by the systematic blending of several clays.

ELECTRIC UNITS AND STANDARDS.*

By J. H. Dellinger.

THE available information on the fundamental electric and magnetic units has hitherto been scattered over an extensive literature. The subject has been condensed and brought up-to-date in this single publication, which gives a unified treatment of the various units, standards, and systems of units. This takes the place of certain previous publications of the Bureau dealing with fragments of the subject.

A unit of any physical quantity is defined in general as a definite amount of that physical quantity, specified in some particular way. A standard is the experimental realization or representation of a unit. A system of units is based upon a few selected independent units; *i.e.*, units defined in terms of an arbitrarily chosen standard. There are three independent units in a system of mechanical quantities, and four in an electrical system.

The basis of the electric units usually used is the electromagnetic system, in which length, mass, time, and magnetic permeability are taken as fundamental. There are several systems of electromagnetic units in use, differing either in the size of the

* Circular No. 60.

fundamental units or in the constants in the defining equations. These are the C.G.S., the so-called "practical," and the Heaviside units. The units used in practice are the "international" units, so called by the international congresses which defined them. They represent the electromagnetic units for practical purposes, and the fundamental international units were so defined as to be equal to the corresponding electromagnetic units as closely as known at the time of definition. The slight differences which have been found by absolute measurements are tabulated in the circular, for the convenience of the occasional investigator who may desire to convert from one system to the other.

The system of concrete standards by which the electric units are now maintained is the result of an evolution extending over 70 years. The units are maintained by the national standardizing laboratories in accordance with the decisions of the 1908 International Conference at London.

The circular gives the definitions of the units and detailed information regarding the units and standards of resistance, current, electromotive force, quantity of electricity, capacity, inductance, power and energy, resistivity, and the magnetic quantities.

In an appendix, conversion factors for the above units are given, both for units of different systems and for the international units as maintained at different times and places. The laws on electric units in different countries are given. A selected bibliography of the literature pertaining to electric and magnetic units and standards is included.

Successful Under-water Coal Storage. J. D. WARDLE. (*Electric Railway Journal,* vol. xlvii, No. 26, June 24, 1916.)—The Iowa Railway and Light Company, which operates about fifty miles of interurban line and has more than 350 miles of high-tension distribution, serving lighting and power consumers in central Iowa, has recently put into service a large under-water coal storage. Iowa coal when piled ignites itself readily, and it is, therefore, necessary to store it in a flooded pit. The coal is reclaimed from the pit with a 15-ton electric locomotive crane. With a consumption of coal of 250 tons a day, it was formerly necessary to carry 5000 or 6000 tons in reserve in cars at a *per diem* charge of 45 cents. With under-water storage the number of reserve cars has been reduced to ten and the daily charge from $45 to $4.50.

Leak Loading of Telephone Lines. ANON. (*Electrical Review*, vol. 68, No. 26, June 24, 1916.)—In the field of wire telephony the series loading of the line with inductors greatly enlarged the possibilities of long-distance telephony. In consequence this subject has been very fully investigated. The leak loading of telephone lines has not proved to be of commercial importance, and little has been published upon the subject, although it is quite possible that the engineers of commercial and operating companies have fully investigated its possibilities from the theoretical standpoint. Lines of this character have been proposed for telephony and cable telegraphy, but their characteristics have not proved favorable.

Prof. Arthur E. Kennelly, of Harvard University and the Massachusetts Institute of Technology, who has worked out the relations involved in leak loading and has developed two new formulas for expressing these relations, contributes a paper on the subject. By taking advantage of the mathematical similarity of the expression for admittance as affected by leaks and the expression for impedance as affected by series inductance, he has reduced the two problems to calculations of the same kind. Numerical examples are given to show the application of the very simple formulas which have been derived. Professor Kennelly is an ardent advocate of the use of hyperbolic functions in electrical computations, and gives here a very good example of the very great advantage and simplicity obtained by their application.

A New Method for Enlarging Photographs Without the Use of a Lens. A. J. LOTKA. (*The Physical Review*, vol. vii, No. 6, June, 1916.)—The method consists in moving the negative to be enlarged past a narrow-slit source of light and, at the same time, moving a sensitive plate under the negative at a speed equal to some constant multiple, n, of the speed of the negative. On development of the sensitive plate, a positive transparency is obtained in which all the lines which were parallel to the slit during the exposure are unaltered, while all lines at right angles to the slit are magnified in the ratio $n:1$. The positive so obtained is subjected to a repetition of the process employed with the original negative, but with the motion at right angles to the lines drawn out n-fold in the first operation. The result of the second operation is a negative geometrically similar to the original, but with the linear dimensions enlarged n times.

Among the advantages which the new method presents is uniformity of illumination over the entire field, absence of optical distortion, compactness, simplicity, and low cost of apparatus. The process necessitates two successive exposures, but this is true, also, of the ordinary method when a negative is to be prepared from a negative. The process and apparatus are protected by U. S. Patent 1,176,384 of March 21, 1916, issued to the author.

NOTES FROM THE NELA RESEARCH LABORATORY.*

NOTES ON FLICKER PHOTOMETRY: FLICKER-PHOTOMETER FREQUENCY AS A FUNCTION OF LIGHT INTENSITY.

By Leonard T. Troland.

THE measurements reported below were partly incidental to some other work, but were thought sufficiently interesting to merit publication.

The conditions of observation were similar to those described in a previous note on the same general subject,[1] except that the standard light consisted of uncorrected tungsten radiation, and a wide range of intensities was employed. The variation of intensity was accomplished by changing the voltage across the standard lamp, so that along with the intensity change there was also an alteration in color. At the highest intensity (1560 photons) the lamp was operating at 1.87 watts per mean spherical candle, and 4.32 volts, while at the lowest intensity (6.4 photons) the voltage across the lamp was 1.33.

The following table shows the flicker-photometer frequencies found under these conditions for eight spectral colors, at the several intensities:

Color	Wave-length in $\mu\mu$	Flicker-photometer frequency, cycles per second, for an intensity (in photons) of						
		6.40	16.0	40.0	100.0	250.0	625.0	1560.0
Red.........	676.4–700.0	8.90	10.66	12.96	16.58	20.78		
		(A.D.) .02	.08	.05	.12	.10		
Orange......	614.4–631.0	10.18	11.76	13.62	16.16	19.74	24.12	28.06
		(A.D.) .04	.09	.10	.05	.08	.10	.12
Yellow.......	569.2–582.0	8.52	9.10	10.26	11.74	14.42	16.52	21.02
		(A.D.) .05	.05	.06	.07	.08	.15	.50
Yellow-green .	534.6–545.0	11.52	13.84	14.78	17.74	19.72	21.66	24.32
		(A.D.) .05	.15	.03	.10	.09	.06	.13
Green.......	500.5–509.0	10.30	11.98	13.70	16.56	20.12	22.28	28.08
		(A.D.) .02	.04	.05	.04	.06	.11	.12
Blue-green...	485.4–493.0	12.34	13.86	16.34	19.48	23.06	26.40	
		(A.D.) .08	.15	.05	.19	.06	.13	
Blue.........	465.0–485.0	13.20	14.60	16.48	19.18	22.02	26.02	29.86
		(A.D.) .07	.13	.06	.08	.08	.05	.17
Violet.......	424.0–436.7	13.02	15.38	18.02	19.66	22.90		
		(A.D.) .13	.17	.08	.10	.18		

* Communicated by the Director.

[1] JOURNAL OF THE FRANKLIN INSTITUTE, vol. 181, No. 6, p. 853.

Each of the values given in the table is the average of five determinations, and the deviation measures are those of the averages themselves.

If the logarithms of the frequencies for any one color are plotted against the logarithms of the intensities, the resulting curve is approximately a straight line for intensities between 40 and 1560 photons. The deviations from straightness below 40 photons are largest for the longer wave-lengths, and are probably to be attributed to the marked orange hue of the standard at these lower intensities. It follows, therefore, that if n is the flicker-photometer frequency, and I the intensity, the relation $n = bI^a$ is approximately true, where b and a are constants. It should be noted that this equation is of quite a different form from that holding for *critical* flicker frequency.

Calculation of the values of these constants for each of the eight colors, on the basis of a representative straight line drawn through the points lying above 16 photons, gives the following results:

Constant	Color							
	Red	Orange	Yellow	Yellow-green	Green	Blue-green	Blue	Violet
b	4.9	6.7	4.4	9.3	6.4	8.5	9.1	10.8
a	.263	.196	.212	.134	.203	.180	.162	.134

It will be noticed that b increases, while a decreases, as wave-length decreases. Although the present measurements are probably sufficiently careful to support this approximate generalization, further work will be necessary to explain the deviations from it. The measurements reported in the previous note indicate that the alteration in the color of the standard, occasioned by the reduction of voltage in decreasing the intensities, has only a second-order effect upon flicker-photometer frequency at intensities in the neighborhood of 500 photons. At lower intensities the effect may be greater.

This work is being repeated under improved conditions.

July 10, 1916.

Corrigenda.—In the article " The Heterochromatic Brightness Discrimination Threshold " (under " Notes from the Nela Re-

search Laboratory"), in the July (1916) number of this JOURNAL, the following changes should be made: On page 113, third paragraph, delete "mentioned." Same page, last paragraph: "v is average of the mean variations of the four intensities, a, b, c, and d; $\Delta I/S$ is expressed as fractions of these intensities;" should read: "v is the average of the mean variations of the four intensities, a, b, c, and d, expressed as fractions of these intensities."

COMPARISON OF THE INTENSITY OF OXIDATION IN LUMINOUS AND NON-LUMINOUS INSECTS.

By W. E. Burge.

THE object of this investigation was to determine if oxidation in luminous insects, such as fire-flies, is more intense than in non-luminous insects, such as moths, butterflies, honey-bees, and bumble-bees, and if oxidation in the luminous tail end of the fire-fly is more intense than in the non-luminous portion.

Method.—The amount of oxygen liberated in 10 minutes from 30 c.c. of hydrogen peroxide by 30 milligrammes of the insect ground up in a mortar with a small amount of sand was taken as a measure of the intensity of the oxidative process of the insect. Burge has shown that tissues in which oxidation is very intense liberate larger amounts of oxygen from hydrogen peroxide than tissues in which oxidation is less intense. The hydrogen peroxide solution used was prepared by diluting the ordinary commercial hydrogen peroxide with an equal volume of distilled water. The apparatus used was an ordinary 100-c.c. burette filled with water to the zero marking and inverted with its mouth in a pan of water. The oxygen gas was conducted into the mouth of the burette by means of a rubber tube from a bottle where the gas was generated when the ground material was mixed with the hydrogen peroxide. The amount of oxygen was read off directly from the burette where it had displaced the water. After this volume had been reduced to standard atmospheric pressure the resulting volume was taken as the amount of oxygen liberated by the material from the hydrogen peroxide.

Experiments.—Thirty milligrammes of fire-flies previously ground up in a mortar with sand were introduced into the bottle containing the 30 c.c. of hydrogen peroxide, and the amount of

oxygen liberated in ten minutes was determined. Ten such determinations were made with an average of 118 c.c. of oxygen for the determinations. The smallest amount obtained in these determinations was 112 c.c. of oxygen, the largest amount 126 c.c. Similarly, 30 milligrammes of a moth were introduced into 30 c.c. of hydrogen peroxide and the amount of oxygen liberated determined. The amount of oxygen liberated by the moth was 8 c.c. of oxygen per 30 milligrammes of material. Determinations were also made using honey-bees, bumble-bees and butterflies. The amount of oxygen liberated in none of these determinations exceeded 25 c.c. of oxygen per 30 milligrammes of material. Thirty milligrammes of the luminous part of fire-flies were cut off and ground up. This part liberated 145 c.c. of oxygen from 30 c.c. of hydrogen peroxide, whereas the same amount of the ground-up non-luminous part of the fire-flies liberated 115 c.c. of oxygen from hydrogen peroxide.

Conclusions.—From the foregoing experiments it may be concluded that the oxidative processes of luminous insects, such as the fire-fly, are much more intense than of non-luminous insects, such as the moth, butterfly, etc.; that the oxidative processes in the luminous part of the fire-fly are probably more intense than in the non-luminous part.

NELA PARK, Cleveland, Ohio, July, 1916.

THE MODE OF ACTION OF ULTRAVIOLET RADIATION IN PRODUCING STERILIZATION.

By W. E. Burge.

IT has been recognized for several years that when living cells, such as bacteria, are exposed to ultraviolet radiation they are killed in a few minutes. Since the life of a cell is dependent upon its intracellular enzymes, and since the ultraviolet radiation destroys enzymes, a theory has been advanced that ultraviolet radiation kills living cells by destroying the enzymes of the cell.

The object of this investigation was to determine if the intracellular enzymes in bacteria are destroyed when the bacteria are killed by exposure to ultraviolet radiation. The bacteria used were pure cultures of *B. prodigiosus*, *B. fluorescens*, *B. liquefaciens*, *B. pyocyaneus*, *B. proteus vulgaris*, and *B. subtilis*. These

bacteria were chosen because they possess the property of liquefying gelatine, this property in turn being dependent upon the intracellular proteolytic enzymes. Twenty-five cubic centimetres of liquid containing great numbers of *B. prodigiosus* were exposed in an open vessel to the radiation from a quartz-mercury vapor burner operating at 140 volts, 3.3 ampères, at a distance of 10 cm., until the bacteria were dead. By means of a centrifugalizing machine the dead bacteria were thrown down and washed in physiological saline. The mass of dead bacteria was ground up in a mortar with sand and 30 per cent. alcohol. In this way the intracellular enzymes were extracted from the dead bacteria. All of the bacteria named above were treated after this manner. Ten cubic centimetres of the alcoholic extract of the different kinds of dead bacteria were introduced into separate test-tubes containing gelatine. Ten cubic centimetres of liquid containing the different kinds of living bacteria were also introduced into tubes containing gelatine. These tubes were permitted to stand at room temperature for 96 hours. At the end of this time the extent to which the gelatine had been liquefied in the different tubes was measured. The extract of dead *B. prodigiosus* had liquefied 7 mm. of gelatine; *B. fluorescens*, 6 mm.; *B. liquefaciens*, 10 mm.; *B. pyocyaneus*, 4 mm.; *B. proteus vulgaris*, 5 mm., and *B. subtilis*, 4 mm. The gelatine in the tube containing living *B. prodigiosus* was liquefied 8 mm.; that containing living *B. fluorescens*, 6 mm.; *B. liquefaciens*, 12 mm.; *B. pyocyaneus*, 5 mm.; *B. proteus vulgaris*, 6 mm., and *B. subtilis*, 4 mm. If the amount of gelatine liquefied by the living bacteria be compared with that liquefied by the extract of the corresponding dead bacteria, it will be found that there is very little difference in the extent of liquefaction. This is taken to mean that, while the ultraviolet rays had killed the bacteria, it had affected very little their intracellular enzymes. These experiments would seem to render untenable the theory that ultraviolet rays kill living cells by destroying their intracellular enzymes.

NELA PARK, Cleveland, Ohio, July, 1916.

Application of a Polar Form of Complex Quantities to the Calculation of Alternating-current Phenomena. N. S. DIAMANT. (*Proceedings of the American Institute of Electrical Engineers,* June 27–30, 1916.)—In the *calculation* of alternating-current phenomena by means of complex quantities, as a rule, the rectangular components of the vector are used, and the rectangular form involving the operator $j = \sqrt{-1}$ is more common than the polar or exponential forms which involve the operators $(\cos \theta + j \sin \theta)$ or $e^{j\theta}$; although it is recognized that the latter are very convenient in certain cases.

A simple method of dealing directly with the vectors themselves is described in the paper, and it consists in introducing the operator j^n, where n, contrary to ordinary usage, may be any positive or negative fraction. Just as j or j^1 rotates the quantity before which it is placed through 1×90 degrees, so j^n rotates the number into which it is multiplied through $n \times 90$ degrees. The operator j^n follows the rule of ordinary algebra, and, according to these, the different algebraic operations of multiplication, etc., are developed. A few illustrative problems are given, followed by a critical *résumé*. A summary of formulas and bibliography are included.

Extinguishing Oil Tank Fires with a Blanket of Foam. ANON. (*Scientific American,* vol. cxv, No. 2, July 8, 1916.)—There is only one effective way to extinguish an oil fire, and that is to smother it; in other words, to cover the burning oil with a suitable form of blanket that will completely cut off the supply of oxygen which is essential to combustion. In the protection of its oil tanks against conflagration the Standard Oil Company of California has met this requirement by developing a liquid extinguisher, which it calls "fire foam." Fire foam is formed by two separate liquors which, when mixed together, result in a thick spume, which readily spreads over a wide area and effectively shuts off the oxygen supply of the burning oil. The two liquids must be separately stored and brought together only just prior to the time when the foam blanket is desired in the blazing tank.

The fire-foam liquors are led through a mixing pipe and discharged through tee heads above the surface of the oil at the centre of the tank, issuing from the outlets in the form of a thick liquid of creamy appearance. The foam rapidly spreads out over the surface of the blazing oil, bubbling as would a huge caldron of dense, boiling liquid. Here and there the flames are seen to reduce in size, eventually to be smothered entirely as the foam blanket becomes more dense. In the period of about a minute the fire is completely extinguished.

SIR WILLIAM RAMSAY.

BIOGRAPHICAL NOTE.

On Monday, July 24, the cables apprised us of the death of Sir William Ramsay, the most distinguished British chemist of our time. This sad news did not come as a surprise to his many friends in this country, for they knew that for several months past he had been bravely fighting against a serious malady. With the passing of Sir William science loses one of its most resourceful experimenters, as well as a most daring prognosticator: one of those investigators who, to use his own phrase, " angle for salmon, but do not fish for sprats." Rather than being satisfied with a sure catch of small fry, he always preferred to take his chances in fishing for a great prize. In some cases he may have mistaken the place where to fish, while in others, perhaps, he used the wrong fly; but, on the whole, the catches he made were of the kind that the most expert angler might well be proud of. His experimental researches in inorganic and physical chemistry extend over a wide range of subjects, although, for the most part, they proceeded from the train of reasoning that led him to the discovery of argon.

He was born in Glasgow, October 2, 1852, and received his early education in the Glasgow Academy. His training as a chemist he acquired in the Universities of Glasgow and Tübingen, at the latter place under Lothar Meyer, who exerted a profound influence upon the young Scotsman's scientific reasoning and imagination.

In 1872 he became assistant in technical chemistry in Anderson's College, and two years later tutorial assistant in the University of Glasgow. While occupying this position his novel and effective methods of laboratory teaching attracted the interest of British educators, and in 1880 he accepted an appointment as Professor of Chemistry in the University College at Bristol. Seven years later he removed to London, where he occupied the chair of chemistry in the University College until his retirement, in 1913, as Professor Emeritus.

It was during the first twenty years of his incumbency of this chair that he made his great discoveries and published his most important books and essays. The only exception is a little laboratory manual for beginners, entitled " Experimental Proofs of

Chemical Theory," which was published about 1880. The simple quantitative methods described in it were promptly and widely adopted both in England and in this country, and may be said to have wrought a revolution in our elementary instruction in chemistry. In 1891 he published an "Elementary Systematic Chemistry," at that time a very novel and valuable treatise on the subject. But his fame as a discoverer dates from 1894, when he joined forces with Lord Rayleigh, the distinguished physicist, in unravelling a mystery disclosed by the latter's researches on the density of nitrogen, and demonstrating that atmospheric air contains the previously unknown gaseous element argon. For the masterly monograph on this subject, describing the discovery and the properties of that most remarkable inert element, the two British investigators were awarded by the Smithsonian Institution the Hodgkins Prize of $10,000, as the most valuable contribution at that time to our knowledge of the atmosphere. The search for argon in terrestrial sources, other than atmospheric air, then led Professor Ramsay to another, and no less important, discovery—that of the gaseous element helium, so called because its spectrum had previously been observed in the photosphere of the Sun (helios). In pondering over the similarity of the characters of the two new elements and their relative atomic weights, Ramsay concluded that there must be other members of the same family in the Periodic System, and that most probably they should also exist in the atmosphere. In the meantime machines had been invented by Professor Linde and by Doctor Hampson for liquefying air and other gases on a large scale by the method of self-intensive refrigeration. Taking advantage of these inventions, Ramsay liquefied large quantities of argon and enormous masses of air, and then subjecting the liquids to careful fractional distillation succeeded in separating from them three new gaseous elements, which he named neon, krypton, and xenon, as well as helium. A careful study of these gases by Ramsay and his co-laborers, especially Doctor Travers, established the fact that they, together with argon, constitute a family in the Periodic System of the chemical elements. Owing to the absolute chemical inertness of these gases, they have thus far found no practical uses, except in a small way, argon being employed in filling certain electric-light bulbs, and helium instead of air or hydrogen in gas thermometers. For this reason, no doubt, these most remarkable

discoveries of Sir William Ramsay have not gained such widespread popularity as some of his later announcements which are less firmly established by experiment, and despite the fact that he has written a most entertaining popular account of this work in "The Gases of the Atmosphere."

About the beginning of the present century the scientific world was startled by the discovery of an entirely new and most remarkable class of substances which have since come to be known as radio-active elements. They differ from the inert gases discovered by Ramsay by their wonderful and continuous activity in sending out rays and "emanations." But the fact that they, too, were obtained from pitchblende—the mineral in which Ramsay had discovered helium—and, further, that the gaseous emanations of radium were chemically inert, suggested to Sir William that these gases might belong to the argon family. So forthwith he proceeded to procure radium compounds, and to prepare and study their gaseous emanation. The circumstance that this radium gas is obtainable only in minute amounts and constantly disintegrating made this work extremely difficult; nevertheless, Sir William and his co-workers (F. Soddy, Cameron, and others) overcame all experimental difficulties, and showed that the emanation obeys the gas laws, that it can be liquefied and solidified, and that it undergoes and causes the most remarkable chemical changes. It was conclusively ascertained by Ramsay and Soddy that the gas in disintegrating produces helium, the first recorded instance of the transformation of one chemical element into another. Although this observation was doubted in many quarters, it has since been verified by independent observers in different countries.

The later researches of Sir William Ramsay proved that radium gas or niton (as he called it) belongs to the argon group. His very numerous researches on the products resulting from its radio-active effects on compounds of various metals and on other gases are highly suggestive, but by no means conclusive. His announcement that he had succeeded in converting copper, for instance, into lithium and other alkali metals, and that he had obtained gases like helium and neon by the aid of electric discharges on hydrogen, etc., have not been confirmed, and, in one instance at least, his assertion has been disproved.

We may hope, however, that this line of work (*i.e.,* the efforts to solve the problem of the transformation of chemical elements

into others, and perhaps even of transmuting the baser metals into the precious) may some day be carried out successfully, and along the lines indicated by the great British chemist.

So far as actual achievements are concerned, his fame is secured by the great experimental researches on the inert gases of the atmosphere and of the radium emanation.

In addition to the books already mentioned, Sir William Ramsay had published a charming volume, entitled "Essays, Biographical and Chemical."

I need hardly mention that his great achievements were recognized in every land where science is cultivated. He was a corresponding member of the great academies, and an honorary member of numerous learned societies. He was Nobel Laureate in Chemistry, and received numerous medals and decorations, among them the Elliott Cresson Medal of The Franklin Institute.

HARRY F. KELLER.

Dissolved Acetylene for Welding. K. DUNHAM. (*Acetylene Journal*, vol. xviii, No. 1, July, 1916.)—Dissolved acetylene, or, as it is more commonly called, tank acetylene, is in wide use by all classes of users. Here gas is bought in ready-made form, ready for use, by the opening of a valve. Care is exercised by the manufacturer of dissolved acetylene to purify it before it is compressed into the cylinder. These cylinders vary in size, according to the needs of the user, from 100 to 500 cubic feet capacity. Since acetylene is dangerous under pressure in a free state, the method of eliminating this hazard is interesting. The cylinder is filled with a porous material, and then acetone, a very volatile liquid, is poured into the cylinder. This acetone absorbs the acetylene, and, as there is no free space in the tank, no danger is encountered in handling or using acetylene furnished in this way.

Acetylene should not be withdrawn from the tank at a rate fast enough to bring out with it the solvent liquid, which is harmful in its effects on molten metal. The flame used should not require an acetylene consumption at a greater rate per hour than one-seventh the capacity of the tank; that is, a 100-foot cylinder should last seven hours. It is for this reason that steel welds made with acetylene from an automobile lighting cylinder are so often unsatisfactory. The gas in automobile cylinders costs more than that in the regular-size welding tanks, and, except in emergencies, the automobile cylinder should never be used. If it is necessary to employ these cylinders instead of welding cylinders it is advisable to connect three or four on a manifold to eliminate the possibility of the withdrawal of the acetone.

THE FRANKLIN INSTITUTE

MEMBERSHIP NOTES.

NECROLOGY.

Mr. Ira D. Bertolet was born at Weissport, Pa., on January 8, 1865, and died on June 19, 1916. He was a member of the Union League, Old York Road Country Club, Philadelphia Chamber of Commerce; a trustee of Albright College, Myerstown, Pa., for about five years, and a trustee of the Christ United Evangelical Church, Philadelphia. Mr. Bertolet became a member of The Franklin Institute in 1907.

Dr. Elmer Lawrence Corthell was born September 30, 1840, at Whitman, Mass., and died at Albany, N. Y., May 16, 1916. He was educated at Brown University, where he received the degrees of Bachelor of Arts, Master of Arts, and Doctor of Science.

He began his career as a civil engineer at Providence, R. I., in 1867. In 1868 he went West and devoted the next two years to railroad work. He was in charge of the construction of the bridge over the Mississippi River at Hannibal, and later served as chief engineer in charge of the construction of the jetties at the mouth of the river. With Mr. Eads, Dr. Corthell went to the Isthmus of Tehuantepec and made surveys for an interoceanic ship-railway. After returning to the United States he spent considerable time in promoting the Eads project for an interoceanic route. The period from 1887 to 1890 was devoted to the design and construction of bridges, railroads, and other large engineering enterprises.

The three succeeding years were devoted to consulting work for the Illinois Central and the Atchison, Topeka and Santa Fé Railway.

Dr. Corthell made extensive improvements in the harbor of Tampico, Mexico, for the Mexican Central Railroad, and was subsequently awarded the Telford Premium and the Watt Medal by the Institution of Civil Engineers of Great Britain for the paper describing this work, which he presented to that body in 1885.

For five years Dr. Corthell was consulting engineer for the Argentine Government, and for eleven years he was engineer for the Boston, Cape Cod and New York Ship Canal.

Dr. Corthell wrote many papers on professional subjects, and was an active member of practically all the important engineering and scientific societies of this country and abroad. He became a member of the Institute in January, 1914.

Prof. Augustus Jay Dubois was born at Newton Falls, Ohio, on April 25, 1849, and died at New Haven, Conn., October 19, 1915.

He received the degrees of Bachelor of Philosophy from Yale University

in 1869, Civil Engineer in 1870, and Doctor of Philosophy in 1873. During the years 1872 and 1873 he attended the Mining Academy in Freiberg, Saxony.

He became Professor of Civil and Mechanical Engineering at Lehigh University in 1875, and in 1877 was appointed Professor of Mechanical Engineering at the Sheffield Scientific School of Yale University. Since 1884 he had been Professor of Civil Engineering at the same institution.

Professor Dubois was the author of a number of works on engineering subjects, and translated and edited the Engineering Classics of Weisbach, Weyrauch, and Röntgen. He was a member of the leading engineering and scientific societies of the world.

Professor Dubois became a member of the Institute on December 20, 1898.

Mr. Charles William Henry Kirchhoff was born at San Francisco, Calif., on March 28, 1853, and died at North Asbury Park, N. J., July 23, 1916.

He obtained his technical education at the Royal School of Mines, at Clausthal, Germany, and graduated in 1874. For three years he was engaged in chemical work in Philadelphia, later becoming managing editor of a metallurgical publication. In 1878 he joined the staff of *The Iron Age,* and in 1881 he became managing editor of the *Engineering and Mining Journal.* Three years later Mr. Kirchhoff returned to *The Iron Age,* first as associate editor and later as editor-in-chief. He retired from the latter position in 1910.

For twenty-three years Mr. Kirchhoff acted as special agent of the United States Geological Survey for the collection of statistics of the production of lead, copper, and zinc.

He was a member of the American Iron and Steel Institute, the Iron and Steel Institute of Great Britain, the American Society of Mechanical Engineers, The Verein Deutscher Eisenhüttenleute, and the Engineers' Club (New York). Mr. Kirchhoff was elected an honorary member of The Franklin Institute in 1899.

Dr. Francis Wyatt was born at Portsmouth, England, in 1854, and died at Forest Hills Gardens, Long Island, on February 27, 1916. He received his early education in his native city, and later studied at the Universities of Brussels and Paris, paying special attention to agricultural chemistry. He came to the United States in 1885, where he established himself as a fermentation chemist and founded the National Brewers' Academy and Consulting Bureau, of which he was president for a number of years.

Dr. Wyatt was known throughout the United States, as well as in Europe, as an eminent authority on the chemistry and biology of fermentation, and won for himself the highest reputation as a brewers' consultant, owing to his wide experience and masterly knowledge of all technical and scientific subjects connected with the fermentation industry. He was an indefatigable worker, student, writer, and lecturer, and his charming personality was such as to immediately attract all those who came into contact with him professionally or socially. Many valuable papers were contributed by him to American and European technical journals relating to theoretical and practical questions of the fermentation industry.

Dr. Wyatt was a member of the Chemists' Club, New York, the American Chemical Society, the Society of Chemical Industry, the Association for Advancement of Science, the American Institute of Mining Engineers, and the British Institute of Brewing. He was an honorary member of the United States Brewers' Association and the Belgian Brewers' Association. He was also a member of the Lambs' Club, New York, the Algonquin Club of Boston, and the University Club of Philadelphia. Dr. Wyatt became a member of the Institute on April 7, 1894.

M. Miguel de Teive e Argollo, Secretary of State, Department of Agriculture, State of Bahia; Member of the Institution of Civil Engineers of London; Commander of the Order of the Rose, died at Paris, France, May 14, 1916. M. Argollo became a member of the Institute in August, 1902.

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An Unprepared Test of a Small Fire Extinguisher. ANON. (*Electrical Railway Journal*, vol. xlvii, No. 26, June 24, 1916.)—The ready advantages of the type of small fire extinguisher containing volatile liquid of low conductivity to electricity were well demonstrated in an accidental manner on June 5, when a fire broke out in the motor windings of an Omaha street car. According to the *Omaha World-Herald*, prompt action with one of these extinguishers subdued the blaze with practically no damage and the car was able to proceed. This result would doubtless have been impossible by using water, which, furthermore, would have been dangerous on account of its property as a conductor of electricity. (Carbon tetrachloride is said to be the liquid employed in one design of these extinguishers.)

CURRENT TOPICS.

Testing Detonators. ANON. (*Mining and Scientific Press,* vol. 112, No. 25, June 17, 1916.)—A detonator is a blasting cap or copper capsule containing a small quantity of some explosive compound that is ignited by a fuse. An electric detonator is one that is ignited by a small wire that becomes heated to incandescence, or fused, by the passage of the electric current. Fulminate of mercury is a well-known detonating agent. It may be mixed with 10 or 20 per cent. of potassium chlorate, and tests have shown that the fulminate alone is inferior to a 90 : 10 mixture, which in turn is inferior to an 80 : 20 mixture.

The United States Bureau of Mines employs "sand tests" for determining the relative efficiencies of detonators. A uniform clean quartz sand of 30 or 40 mesh is employed. The sand is placed in a small steel case, which has thick walls and a cover. The detonator is fired in the centre of a mass of 100 grammes of standard sand placed within the cavity. The extent to which the sand is pulverized by the detonation, as measured by screening tests, indicates the efficiency of the detonator. It has been assumed that a high speed of detonation is an essential property of a detonator. This is not so. Many explosives, such as blasting gelatin and nitroglycerin, have a higher velocity of detonation than fulminate of mercury, but they have not the property that fits them for use as initial detonators. It appears that the explosion of mercury fulminate results in an intense local action in the form of a sudden blow.

Former methods of making tests, in which the detonators were fired in lead blocks or their influence tried on other detonators at various distances, had proved unsatisfactory, the sand test being now preferred for careful work. However, a simple test can be made with a 4-inch wire finishing nail. The detonator is fired in proximity to the nail, and the resultant bend in the nail indicates the strength of the explosion. The strength of fulminate detonators is said to be unaffected by becoming moist, although detonators of trinitrotoluene are weakened by moisture. The trinitrotoluene detonators may become entirely unserviceable after storage for a month in a damp magazine.

Prevention of Dust Explosions and Fires in Grain Separators. ANON. (*Weekly News Letter,* U. S. Department of Agriculture, vol. iii, No. 43, May 31, 1916.)—As a result of a study of explosions in threshing machines, the department now recommends that one or more of three measures be adopted to prevent loss from this cause.

These are: (1) The installation of an efficient grounding system for the removal of static electricity from the machine; (2) the installation of a suction fan to remove smut and dust and to prevent the formation of an explosive mixture of dust and air while the threshing is being carried on; and (3) the installation of a device to act as an automatic fire extinguisher which in the event of fire will not only save the machine but will prevent the flames from spreading to the surrounding grain.

The first two of these devices have been tried with successful results in the field. The automatic fire extinguisher was not constructed until the threshing season had been closed, but it has been tested under severe conditions in the explosion galleries of the Bureau of Mines at Pittsburgh, and in these tests it has operated successfully. It has also been tested under practical threshing conditions at the government farm at Arlington, and has proved effective in extinguishing fires which were produced in different types of grain separators there. Blue prints of each of these devices may be secured upon application to the office of Public Roads and Rural Engineering of the department at Washington.

The best method, the investigations indicate, for carrying off any static electricity that may be produced is to connect wires from all moving parts on the machine to one wire and to ground that wire. The suction fan is arranged to exhaust from above the cylinder and also from beneath the pan. While it is pointed out that there is no way of absolutely demonstrating that either the grounding of the machine or the suction fan actually prevents explosions, the fact remains that no such occurrences have taken place, so far as is known, with separators that were properly equipped in this way. These devices, however, do not remove all danger from fire, for, in addition to electric sparks, foreign materials which find entrance into the separator may start fires, and for this reason the automatic fire extinguisher is regarded as a desirable additional protection.

Theory and Practice in the Filtration of Water. W. CLEMENCE. (*The Journal of the Institution of Mechanical Engineers*, May, 1916.)—Open sand-filters for purifying waters for potable purposes have now been in use for nearly a century, and since 1830 they have been continuously used in connection with the London water supply. The first sand-filtration plant, designed by James Simpson for the Chelsea Water Company, consisted of decanting basins in which the raw water could be kept at rest for twelve hours, and open filter-basins in which a layer of fine sand 2 feet 6 inches deep was placed on a bed of gravel of about the same thickness. In the gravel bed brick collecting drains with arched covers were constructed. These large drains were found to induce a too rapid flow of water through the sand immediately over them, and in later practice smaller drains were used which were distributed over the whole area of the floor of the filter to secure an even speed through the bed.

During the last twenty years what is known as the "mechanical filter" has been introduced, in which the arrangement of filtering material differs little in section from that adopted in open sand-beds, but the water under treatment is passed through the materials at a speed from twenty to sixty times greater than that which has been found in practice to represent a safe limit of speed with slow sand-filters in order to obtain complete purification of the water. This limit is generally agreed upon to be from 50 to 75 gallons per square foot per 24 hours, and it is obvious that if the process of purification is found to be incomplete in the slow filter, on exceeding this speed it must be more so in the rapid filter.

With filters of fine sand working at a slow speed it is found that practically all matters in suspension in the water, whether living organisms or silt particles, are retained on the surface of the filtering medium, where they eventually form an impervious layer, and it becomes necessary to remove this in order to restore the permeability of the bed. It has been established in practice that with filters on which a filtering layer is allowed to form the efficiency of the filter is impaired if the layer is disturbed, and that after its complete removal when the filter is cleaned the chemical and bacterial efficiency is not restored until a film has again formed.

Much attention has been paid by engineers in recent years to the improvement in the conditions of working and the design of filters, resulting in the formation of two distinct methods of practice, based on widely divergent theories. On the one hand, those who support the theory that the bacterial purification of water by filtration is chiefly due to the mechanical action have developed the mechanical filter, in which a film is created artificially by the use of a coagulant, and a high speed is adopted. On the other hand, Armand Pusch proved by experiment and observation that the formation of a film on the surface of a filter was a hindrance rather than an aid to purification, and Pusch and Chabal have developed the system of multiple filtration, which is founded on the now ascertained fact that the formation of a film, either natural or artificial, on the surface of the filtering medium is unnecessary and undesirable.

New Car for Fish Distribution. ANON. (*United States Commerce Reports*, No. 159, July 8, 1916.)—A new car for the Bureau of Fisheries, designed for carrying live fishes long distances, has lately been completed and is receiving its special equipment preparatory to being placed in commission. The car is entirely of steel and is thoroughly insulated by the latest improved method to insure against heat and cold. It has a length of 60 feet ½ inch over ends of body plates, and a standard width of 10 feet. The weight of the car with equipment is 150,000 pounds, and is designed to carry a load of 35,000 pounds. In the centre, running lengthwise on each side, are insulated tanks with a total capacity for 130 ten-gallon cans in which fish are held. During transportation the fish will be fur-

nished with oxygen and fresh water by means of air- and water-pumps, operated by a 6-horse-power steam boiler. The boiler will also furnish heat to the car, but, in addition to this independent heating system, the usual train attachment for heating from the locomotive is provided. Tanks for carrying a reserve water supply are located beneath the car, and an ice-box having a capacity of one ton is provided. In addition to the facilities for the transportation of fish, the car is fitted with living accommodations for a crew of five men, a cook's galley, an office, and a space for a dining table.

Fish are distributed by the Bureau of Fisheries in every State of the Union, some 10,000 individual applications being filled annually in addition to the large public plants of the so-called commercial species in the Great Lakes and coastal streams of the seaboards. This phase of the bureau's work has grown to enormous proportions, and in the fiscal year ended June 30, 1915, 49 species were propagated, these including, in addition to fishes, the lobster and several species of fresh-water mussels. The total output of these was over four and a half billions, which were planted in every State and in Alaska. Some idea of the magnitude of the work of distributing fish is indicated by the fact that it involved 637,716 miles of travel, of which 146,544 was by the bureau's special cars and the remainder by car messengers.

The Flow of Viscous Liquids through Pipes. W. K. LEWIS. (*The Journal of Industrial and Engineering Chemistry*, vol. 8, No. 7, July, 1916.)—The carrying capacity of pipes for water under various pressure-drops has been experimentally studied by many engineers, and, while the results are not very concordant on account of the extreme sensitiveness to varying conditions, none the less our knowledge of the resistance to flow of water through pipe lines is relatively satisfactory and complete. On the other hand, practically no work has been published on the resistance to flow through pipes of liquids other than water, despite the fact that information of this sort is of vital importance to the chemical engineer.

It has long been known that, for the flow of liquids through capillary tubes up to 4 or 5 mm. in diameter, according to the formula of Poiseuille, the pressure-drop varies as the viscosity, length, mean velocity, and inversely as the radius squared. Though quantitative data have not been published for the flow of liquids other than water through large tubes or pipes, the paths along which the particles of liquid travel have been studied qualitatively by introducing air or dyes into the fluids and photographing the effects produced by forcing them through glass containers of various shapes and sizes. These observations show that at low velocities liquids move in straight lines parallel to the axis of the tube, but, when the velocity is sufficiently increased, the lines of flow become distorted, the filament forming violent eddies of constantly changing form and position. At the walls of the container there is always a film of

liquid which is retarded by the friction of the solid surface so that it continues to move in straight lines. The mean velocity of the fluid at the point where the change in type of motion takes place is commonly known as the critical velocity, and all flow below this point is called parallel, direct, or viscous motion, while that above is known as turbulent, indirect, or sinuous flow.

Liquids of even moderate viscosity flowing under low heads follow viscous motion, unless the pipes be very large. It is very important to keep in mind the fact that, so long as the motion is viscous, doubling the size of the pipe increases the velocity four-fold and the discharge sixteen-fold for the same pressure-drop. Decrease in size will ultimately result in converting the flow into sinuous motion, after which the effect of size is greatly lessened, being inversely proportioned only to the first power of the diameter.

Railway Motor Field Control. D. C. HERSHBERGER. (*Electric Railway Journal*, vol. xlvii, No. 26, June 24, 1916.)—The prime object of field control is to permit more efficient operation, and, although a field-control equipment is somewhat more expensive in first cost than one without field control, it may be an unwise policy to purchase a non-field control equipment. It has been found in many cases that field-control equipments pay for the additional first cost in two to three years; after this the saving is so much net gain.

Field control has in recent years been applied to all classes of railway service, and the indications are that it will be applied to far greater extent in the future. To date the application of field-control motors in the country amounts to approximately 840,000 horsepower, distributed among some fifty operating companies. It is difficult to determine the total annual saving effected by the use of the field-control motor; it is, however, estimated at approximately one-third of a million dollars per year.

The Corona Voltmeter. J. B. WHITEHEAD and M. W. PULLEN. (*Proceedings of the American Institute of Electrical Engineers*, June 27–30, 1916.)—During a number of years' intermittent experiment on the phenomena attending the electric breakdown of air, one of the most striking observations has been the extreme sharpness, in an ascending range of voltage values, with which this breakdown occurs in the form of corona on clean, round wires. It has been shown beyond question that the appearance of corona depends on the maximum value of the alternating-current wave. Under suitable conditions of observation critical voltage readings repeat themselves with an accuracy equal to that within which the usual direct reading instrument can be read, *i.e.*, of the order of one-tenth of one per cent. Three methods for detecting the first appearance of corona have been developed, in addition to the method of usual observation. These methods involve the use of the electroscope, the galvanometer, and the telephone respectively.

For a given wire, in fixed relation to the opposite side of the circuit, corona-forming voltage depends on the density of the air; that is, on the pressure and temperature. The corona voltmeter consists of a grounded metal cylinder with a central conductor on which corona is formed. Both cylinder and conductor are enclosed in a larger air-tight cylinder, in which the pressure can be varied by a hand-pump. This variation in pressure provides the means by which a wide range of voltage reading is possible. The calibration of the instrument is absolute; that is, it can be calculated or obtained by comparison with existing standards.

The voltmeter is set for a given voltage by adjusting the pressure to a value calculated from the dimensions of the instrument, taken from a calibration table or curve. When the ascending voltage reaches the value for which the voltmeter is set, corona begins, and this is sharply indicated by any one of the three methods mentioned. To measure an unknown voltage, the pressure is gradually lowered from some higher value and is read at the instant corona appears. A calibration curve then gives the unknown voltage.

Kerosene Automobile Engines. C. E. LUCKE. (*Bulletin of the Society of Automobile Engineers*, vol. x, No. 3, June, 1916.)—Use of kerosene in standard gasoline equipment does not produce what can be regarded as satisfactory results from the operating stand-point, because, even in addition to the requirement of gasoline for starting purposes, the kerosene is so little vaporized as to involve troubles of the following well-known order: (*a*) Bad header distribution between carburetor and the several intakes resulting in unequal charges to the several cylinders; (*b*) excessive washing down of lubricating oil from the cylinder walls, due to its solubility in kerosene—proved by the accumulation of kerosene in the crank-case oil; (*c*) smoke and smell in the exhaust or internal carbon, due to decomposition of heavy, unvaporized kerosene drops and wall films, or late vaporizing oil unmixed with air, by the explosion heat of the unmixed part; (*d*) misfires and backfires, due to variations in the mixture as a result of varying degrees of vaporization of the oil that passes the carburetor as the engine temperature varies—especially noticeable with change of throttle, engine speed, or load.

The trouble encountered can be generalized as due to excessively wet mixtures or, inversely stated, to incomplete vaporization, and even to mixtures of a variable degree of vaporization. No particular knowledge of the properties of vapors or of vapor-air mixtures is required to realize that the sort of corrective needed is heat, but it makes all the difference in the world just how the heat is applied. The scientific knowledge of the properties of hydrocarbon liquids and vapors and their vapor-laden mixtures, and the laws of heat transmission through metal walls to get warm mixtures, is no more than sufficient than to indicate just where, how, and to what degree the heat application is to be made.

The problem of adaptation of the gasoline automobile engine to the use of heavier fuels than will vaporize satisfactorily with air without the use of heat is entirely a problem of heating and heaters. Given suitable data on the amount of heat required, on the temperature that should be maintained, on the design of suitable heaters, in shape arrangement and size, on the source or available supplies of heat, on means of establishing and maintaining as long as necessary a suitable starting heat, on the connection between the heated mixture-making apparatus and the engine, and, finally, on the modifications required in the engine so that it will operate properly on the mixtures hot enough to burn without oil or residue, carbon deposits, or smoke—given such data, the kerosene automobile engine can be designed by any engineer. Of course, all this is not available at the present time, but enough is available to put quite satisfactory results within reach now with the ordinary expectation of improvement, perfection, and standardization of such equipment each year of successive use.

"Stainless" Steel. ANON. (*La Chronique Industrielle*, vol. 39, No. 256, June 11, 1916.)—A new alloy of steel, styled "Stainless," containing the notable proportion of 12 per cent. of chromium, has lately come into use in England. It is used with success for cutlery, but its principal advantage is its great resistance to corrosion. According to recent analyses, its typical composition is: Carbon, 0.28 per cent.; silicon, 0.01 per cent.; manganese, 0.12 per cent.; chromium, 12.7 per cent.; cobalt, 0.45 per cent.; iron, 86.6 per cent. In contact with foodstuffs and acids, this steel resists all rusting and tarnishing. Some interesting experiments are now being carried on in England with a view to its application in harbor structures, where the corrosion of structural steel is a serious menace.

Switching Cars by Magnetic Coupling. ANON. (*Scientific American*, vol. cxv, No. 1, July 1, 1916.)—The value of the lifting magnet as a substitute for the crane, hood and shackles is amply demonstrated by its extensive adoption in shops and yards where materials of iron have to be economically handled. Some idea of the holding power of these magnets may be obtained by endeavoring to release from its hold such a small article as a 16-ounce hammer. When fully energized all ordinary effort to a person of average strength is insufficient to separate the hammer from the pole-piece.

At Berne, Switzerland, the authorities have developed this method of connection in the form of magnetic couplers for train-yard switching service. The locomotive is of the storage-battery type, capable of doing a day's work without recharging. At the two ends of the locomotive, and directly opposite where the buffers project from a neighboring car, the tractor has two magnetic buffers controlled by the driver, like the lifting magnet of a crane, and coupling or uncoupling is merely a matter of turning a switch. It takes 440

watts to energize the magnets in service, and the tractive force that can be resisted is 7480 pounds. The pole-pieces are shaped to conform to the buffers to secure good contact, but even with a gap of two-tenths of an inch each magnet is effective for a tractive force of 1980 pounds.

The Synthetic Ruby. ANON. (*La Chronique Industrielle*, vol. 39, No. 256, June 11, 1916.)—For many years chemists and engineers have sought to produce by artificial means and in generous quantity that which Nature had parsimoniously doled out in the course of long ages. Analysis of various gems demonstrated that they were nothing else than alum, crystallized under special conditions. In keeping with the metallic salt present while the gem was in fusion, there resulted the different varieties of stones known under the name sapphire, ruby, topaz, amethyst, or emerald. The one great difficulty to the progress of early investigators lay in the production of the high temperatures necessary for a solution of the problem, and the introduction of the oxyhydrogen torch marked the beginning of the artificial gem industry.

The practical production of artificial gems is due to Verneuil. The basic material is ammonia alum, which is heated in muffles to convert it into calcined alum. To this is added the coloring matter in given proportions: oxide of chromium for rubies, titanic acid for the sapphire. This finely divided powder is allowed to trickle through into the oxyhydrogen flame, which attains a temperature of 1800°. The powder fuses, resulting in the formation of an inverted, pear-shaped body weighing from 10 to 200 carats (1 carat = 0.2 gramme).

Prior to the discovery of the synthetic method now in use, the manufacture of the so-called reconstructed ruby was exploited. These gems are formed by the fusion of a number of small rubies of uniform tint into a larger mass. Many large rubies of the present day have been obtained by this process. It is difficult to fix the date of the origin of the process, those who first conceived it having jealously guarded the secret. At the present time it is entirely abandoned in favor of the synthetic method. These stones have an important industrial value as a bearing material in the running gear of various instruments, and the cheapening of their production is of material advantage in the manufacture of such mechanisms.

Alcohol-benzol Mixture as Fuel for Automobiles. J. E. JONES. (*U. S. Commerce Reports*, No. 164, July 14, 1916.)—According to an article appearing in *Le Progres*, a daily newspaper published at Lyon, among the many efforts made by Germany to counteract the effects of a blockade, one of especial interest is the replacing of gasoline for automobiles by a mixture of alcohol and benzol. With the cessation of imports of gasoline into Germany, the supplies of petroleum drawn from wells in Galicia proved inadequate for the

needs of the Central States. For this reason the German Government instructed the technical department of the transportation service to seek a combustible that would effectively replace gasoline. The outcome of these experiments was the employment of a mixture of alcohol and benzol.

A Mercedes car of the 1914 touring model, having an ordinary carburetor, was used for experimenting purposes. The best result was obtained with a mixture of one part of benzol to one of alcohol, the duty in miles per pint of the fuel being 4.66. Increasing the proportion of alcohol to five parts, the duty continuously lowered to 3.72. With benzol alone, the duty was 3.79; with gasoline, 3.60. At normal prices the use of such a mixture is an economy. One pint of gasoline costs 8.55 cents; benzol, 8.17 cents, and alcohol, 7.79 cents. The difficulty of starting with the alcohol-benzol mixture was overcome by using a supplementary gasoline, benzine, or ether supply until the engine warmed up.

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THE HENRICI HARMONIC ANALYZER AND DEVICES FOR EXTENDING AND FACILITATING ITS USE.*

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CONTENTS.

HARMONIC ANALYSIS.

The harmonic method of analysis, based upon Fourier's Theorem, first published in "La Théorie Analytique de la Chaleur" (Paris, 1822), is of very great value in the investigation of many phenomena which can be represented by curves, and especially of wave motions which are represented by periodic curves. This theorem may be stated as follows: If any curve be given, having a wave-length l, the same curve can always be reproduced,

* Communicated by the Author.

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and in one particular way only, by compounding simple harmonic curves of suitable amplitudes and phases, in general infinite in number, having the same axis and having wave-lengths of l, $\frac{1}{2} l$, $\frac{1}{3} l$, and successive aliquot parts of l. The given curve may have any arbitrary form whatever, including any number of straight portions, provided that the ordinate of the curve is always finite and that the projection on the axis of a point describing the curve moves always in the same direction.[1, 2] The practical significance of this theorem and the complete processes of harmonic analysis and synthesis have been explained in detail and graphically illustrated elsewhere by the author.[3, 4]

The mathematical expression for a curve, derived in accordance with Fourier's Theorem, consists of an infinite trigonometric series of sines and cosines, which may be stated as follows:

$$y=\frac{1}{l}\int_0^l y\,dx+\begin{cases}\left[\frac{2}{l}\int_0^l y\sin\frac{2\pi x}{l}dx\right]\sin\frac{2\pi x}{l}+\left[\frac{2}{l}\int_0^l y\sin\frac{4\pi x}{l}dx\right]\sin\frac{4\pi x}{l}+\cdots\\ \left[\frac{2}{l}\int_0^l y\cos\frac{2\pi x}{l}dx\right]\cos\frac{2\pi x}{l}+\left[\frac{2}{l}\int_0^l y\cos\frac{4\pi x}{l}dx\right]\cos\frac{4\pi x}{l}+\cdots\end{cases}\qquad \text{I}$$

in which y is the ordinate of the original complex curve at any point x on the base line, and l is the fundamental wave-length.

For the purposes of mathematical treatment it is convenient to express the abscissæ x in terms of angular measure, θ radians, with such a unit that the wave-length l equals 2π radians. The equation then has the form,

$$y=\frac{1}{2\pi}\int_0^{2\pi} y\,d\theta+\begin{cases}\left[\frac{1}{\pi}\int_0^{2\pi} y\sin\theta\,d\theta\right]\sin\theta+\left[\frac{1}{\pi}\int_0^{2\pi} y\sin 2\theta\,d\theta\right]\sin 2\theta+\cdots\\ \left[\frac{1}{\pi}\int_0^{2\pi} y\cos\theta\,d\theta\right]\cos\theta+\left[\frac{1}{\pi}\int_0^{2\pi} y\cos 2\theta\,d\theta\right]\cos 2\theta+\cdots\end{cases}\qquad \text{II}$$

If the first term is represented by a_0, and the coefficients of the sine and cosine terms, the quantities in square brackets are represented by a_1, b_1, a_2, etc., the equation will have the following symbolic form of simpler appearance:

$$y=a_0+\begin{cases}a_1\sin\theta+a_2\sin 2\theta+\ldots\\ b_1\cos\theta+b_2\cos 2\theta+\ldots\end{cases}\qquad \text{III}$$

The term a_0 is a constant and is equal to the distance from the line assumed as a base to the true axis of the curve; if the base coincides with the axis, $a_0 = 0$, and this term does not appear in the equation of the curve. This term has no relation to the form or

significance of the curve, and usually its value is not required; it may be determined, however, by means of an ordinary planimeter, as described in the reference.[3]

The other terms of the equation occur in pairs, as $a_1 \sin\theta$, $b_1 \cos\theta$, etc., and each term, whether a sine or a cosine, represents a simple harmonic curve. The successive terms of the series of sines and of cosines repeat themselves with frequencies of 1, 2, 3, etc., which means that the curves have wave-lengths in the proportion of $1 : \frac{1}{2} : \frac{1}{3}$: etc.; such a succession of terms is said to form a *harmonic* series.

The coefficients of the various terms, the quantities in square brackets in equation I, which are represented by a_1, b_1, a_2, etc., in equation III, have the following general form, n being the *order* of the term and l the wave-length:[1, 2]

$$\frac{2}{l}\int_0^l y \sin \frac{2n\pi x}{l}\, dx.$$

Each coefficient is a number or factor indicating how much of the corresponding simple sine or cosine curve enters into the composite; that is, it shows the height or *amplitude* of the simple component.

The process of *analyzing a curve* consists of finding the particular numerical values of the coefficients of the Fourier equation so that it shall represent the curve. In general the number of terms required is indefinitely great, or even infinite, but in many instances a finite number of terms is sufficient. Whenever certain of the simple curves are not required, the corresponding coefficients are said to have the value zero, and their terms do not appear in the equation of the curve. In the study of sound waves the number of terms involved seldom exceeds thirty and often does not exceed ten. Fourier showed how the numerical values of the coefficients may be calculated, but the process is very long and tedious, requiring perhaps several days' work for a single curve. The great importance of harmonic analysis has caused the development of many methods, numerical, graphical, and mechanical, for facilitating the calculations.[3] The main part of each coefficient is a definite integral which is of the nature of an area, and various area-integrating machines, known in their simpler forms as *planimeters*, may be adapted to the evaluation of these coefficients. A complete apparatus arranged for mechanically deriving the Fourier equation of a curve is called a *harmonic analyzer*.

Perhaps the most convenient and precise harmonic analyzer yet devised is that of Henrici. An instrument of this type has been in use by the author since 1908 in the study of sound waves, and with it several thousand curves have been analyzed. The experience thus gained has led to the development of various instruments and methods for facilitating the analytical work, both with this particular form of analyzer and in general. It is the purpose of this paper to describe these devices.

HENRICI'S HARMONIC ANALYZER FOR TEN COMPONENTS.

The harmonic analyzer devised by Prof. O. Henrici, of London, is based upon the rolling sphere integrator, and its theory was first published in 1894.[5] These analyzers have been developed and mechanically perfected by Mr. G. Coradi, of Zurich; and, as constructed by him, they are not only of beautiful workmanship, but they are also calculating machines of high precision. An analyzer of this type, with five integrating apparatus, is shown in Fig. 1. The theory of the Henrici analyzer will be stated very briefly.

The general expressions for the coefficients of the sine and cosine terms of the Fourier equation, form II (represented by a_1, b_1, etc., in form III), integrated by parts, give the following equations, n being the order of the term:

$$a_n = \frac{1}{\pi}\int_0^{2\pi} y \sin n\theta d\theta$$

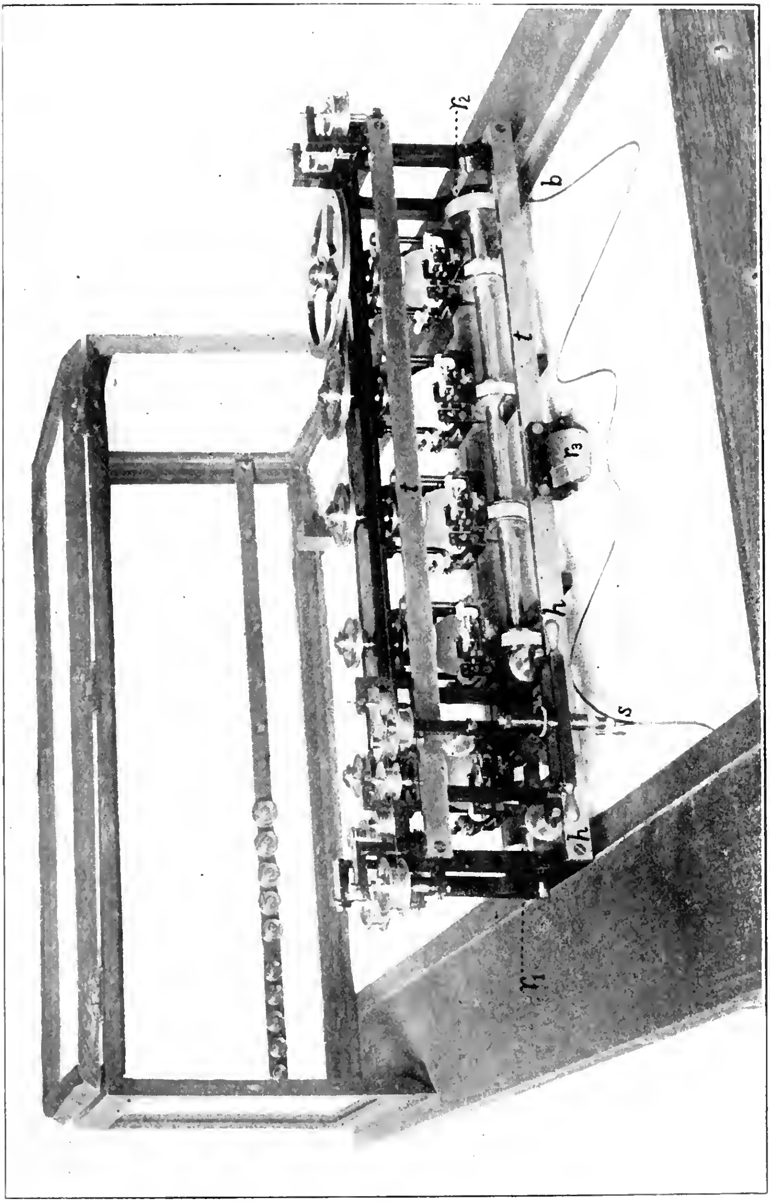
$$= \left[-\frac{1}{n\pi} y \cos n\theta\right]_0^{2\pi} + \frac{1}{n\pi}\int_0^{2\pi} \cos n\theta dy,$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} y \cos n\theta d\theta$$

$$= \left[\frac{1}{n\pi} y \sin n\theta\right]_0^{2\pi} - \frac{1}{n\pi}\int_0^{2\pi} \sin n\theta dy$$

If the curve is continuous, and if the initial and final values of y are equal, the terms in square brackets disappear. Nearly all the curves representing physical phenomena satisfy these conditions. If the curve has a discontinuity, it is made continuous

FIG. 1.



Henrici harmonic analyzer.

for purposes of analysis by joining the two points of discontinuity by a straight line; and if the final value of y is not equal to the initial value, that is, if the curve does not end on the base line, it is brought back to the base by a straight line parallel to the ordinate y. Under these conditions it can be proved that the integrals already given properly measure the coefficients of the Fourier equation of the curve. Further, if the base line is added to the path of integration, nothing is added to the value of the integral, since for this part of the path $dy = 0$, and the integral is taken around a closed curve.

Therefore the *Henrici integrals*, which define the values of the coefficients of the Fourier equation of the curve, have for the sine terms the form, n being the order of the term,

$$a_n = \frac{1}{n\pi} \int_{\theta=0}^{\theta=2\pi} \cos n\theta dy,$$

and for the cosine terms the form,

$$b_n = -\frac{1}{n\pi} \int_{\theta=0}^{\theta=2\pi} \sin n\theta dy.$$

It will be noticed that the coefficients of the sine terms contain cosine integrals, and *vice versa*.

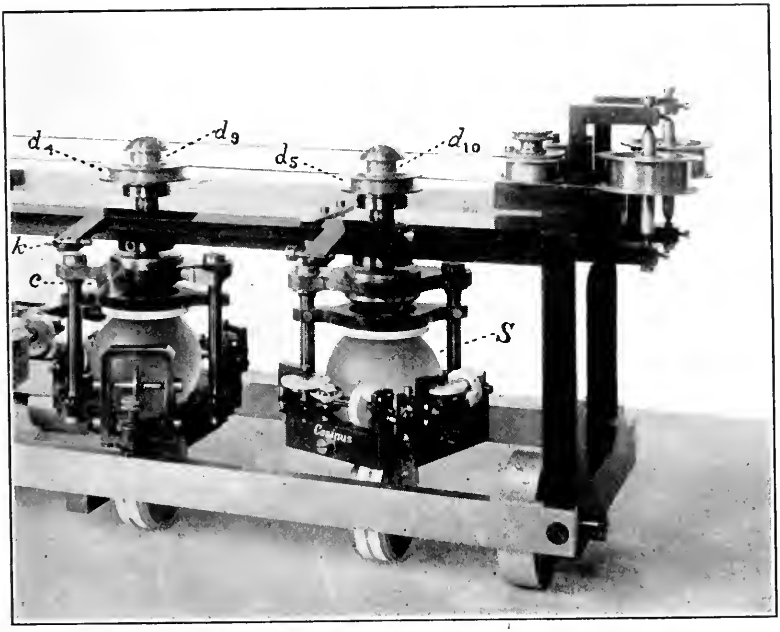
For the evaluation of any a coefficient, as the nth, it is necessary that each element of amplitude dy of the original curve shall be multiplied by the instantaneous value of $\cos n\theta$ and that the whole be integrated between the limits $\theta = 0$ and $\theta = 2\pi$; for the b coefficients the operation is the same, except that the resolving factor is $\sin n\theta$. The analyzer, then, is an integrating machine for evaluating these special integrals, and it may be arranged with one or more integrators, each of which at one operation determines one pair of integrals defining the term of a certain order. The integrations for the terms of various orders differ only as regards the factor n. The actual readings given by the dials of the integrators for any term are n times the values of the above integrals; that is, they are na_n and nb_n.

For the proper performance of its function of integration it is necessary that each integrator shall receive the effects of two rectangular motions which are related to the area of the curve in certain particular ways as required by the development of

Fourier's theorem. One of these movements is secured by the rolling of the instrument as a whole, back and forth parallel to itself, while the second is obtained from the movement of a carriage along a transverse track.

The analyzer is supported by three rollers, r_1, r_2, and r_3, Fig. 1. The curve to be analyzed, which must be drawn to a specified scale, is placed underneath, and is adjusted so that its axis (or base) is parallel to the track *t;* this condition may be determined by

FIG. 2.



The rolling sphere integrator.

inspection or by moving the carriage with the stylus *s* along the track and adjusting the curve until the stylus traces the given line. If no base line is given, any line touching the crests or troughs of two consecutive waves, or any parallel to such a line, may be used. The stylus is placed over the initial point of the curve, as shown; the stylus is adjustable in a transverse slot to facilitate this setting. The initial point may be chosen at convenience, since the analyses of a curve made from different starting points will (when fully reduced) differ only in the phases of the components. The

handles h are grasped with the fingers and the stylus is caused to trace one exact wave-length of the curve, when it will again be on the base line, at the point b; the stylus is returned to the starting point s, along the assumed base line, completing the integration around a closed curve. The latter operation theoretically adds nothing to the value of the integral, while it eliminates errors which would be produced if the axes on which the integrators revolve do not pass through the centre of the axle a. The tracing of the curve will have required a combination of the two specified rectangular movements, and the manner of communicating these in the proper proportion to the integrators will be now described in detail.

FIG. 3.

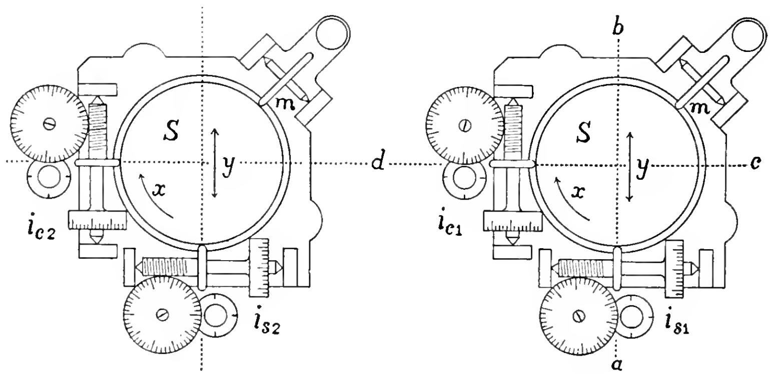


Diagram of two rolling sphere integrators in initial positions.

The rolling sphere integrator has for its essential parts a sphere of glass, S, Fig. 2, which when in use rests upon a celluloid roller underneath it at what may be called the south pole, and two integrating cylinders, i_{s_1} and i_{c_1}, Fig. 3, which rest against the equatorial circumference of the sphere and, while revolving around the sphere, always touch it at points 90 degrees apart. A third roller, m, holds the sphere against the integrating wheels with a spring pressure. When not in use, each sphere may be lifted from all the rollers and be held securely between celluloid clamping rings. In this condition the integrating cylinders are free to move, and each may be set so that its dials indicate zero, preparatory to the operation of tracing a curve.

The rollers r_1 and r_2, Fig. 1, and the five celluloid rollers underneath the spheres are all rigidly attached to the same axle a; the

celluloid rollers, being smaller than the others, do not touch the paper.

As the curve is traced the machine rolls backward and forward, parallel to itself, the five spheres are *all rotated* by the *same amount,* and in the *same direction,* the direction of the amplitude of the curve, as indicated by the arrow y, Fig. 3. The amount of this rotation is always proportional to the amplitude y of the complex curve, and, therefore, at *each point* in the tracing, it is proportional to the instantaneous sum of the separate component amplitudes of the simple component curves.

The integrating cylinders i_s are for evaluating the sine coefficients and i_c for the cosines. Each pair of cylinders is attached

FIG. 4.

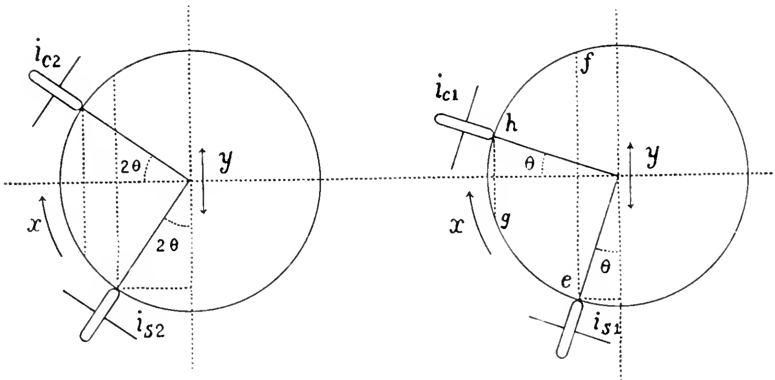


Diagram of rolling sphere integrators after the stylus has moved the distance $x = \theta$.

to a light frame which surrounds the equatorial region of the sphere, Figs. 2 and 3; the frame is supported from above and is capable of rotation independently of the sphere, on an axis in the prolongation of the north polar axis, as indicated by the arrows x. The initial or zero positions of the cylinders are shown in Fig. 1 and 3, the settings for which are facilitated by clamping screws c and spring stops k, Fig. 2. In this position $\theta = 0$, and when the instrument rolls in amplitude the sphere rolls in the plane ab and the integrating cylinder i_{s_1} records a rotation proportional to $dy \cos \theta$, and i_{c_1}, which touches the sphere at a point on the axis of rotation cd, has a rotation proportional to $dy \sin \theta$; that is, it is not rotated at all (for $\theta = 0$, $\cos \theta = 1$, and $\sin \theta = 0$).

When the stylus, in tracing the curve, has moved in the direction of the x axis by an amount equal to θ, the integrating cylinders

for the first component must be revolved (as described later) around the first sphere through an angle θ, Fig. 4, the integrators for the second component must revolve through an angle 2θ, and for any higher component the cylinders must be revolved through an angle $n\theta$. In the position shown in Fig. 4 the integrator i_{s_1}, which has moved through the angle θ, now touches the sphere on the circumference of a circle of diameter ef, and as the sphere rolls in amplitude by the amount dy, the cylinder receives a rotation proportional to $dy \cos \theta$; the integrator i_{c_1} touches the sphere on the circumference of the circle gh and it is rotated by an amount proportional to $dy \sin \theta$. The integrators i_{s_2} and i_{c_2} have at the same instant been revolved through the angle 2θ and they receive rotations proportional to $dy \cos 2\theta$ and $dy \sin 2\theta$, respectively. The integrators arranged for terms of other orders operate in a corresponding manner.

For the evaluation of the first component of a curve, the fundamental, the sine and cosine integrating cylinders must be carried around the sphere *exactly* one revolution while the stylus traces one fundamental wave-length of the curve, and for the second component the cylinders must revolve twice in the fundamental wave-length, and for the third component the cylinders must revolve three times in the same interval, etc. This revolution of the cylinders is accomplished by attaching a wire to the carriage of the stylus, which passes around fixed guide pulleys and is wrapped once around suitable disks, d_1, d_2, etc., Figs. 2 and 5, attached to the upper parts of the spindles which support the frames of the cylinders. One integrator may be used for evaluating any number of terms (one at a time) by supplying a series of disks suitable for turning the apparatus once, twice, three times, and so on, while the stylus traces the fundamental wave-length. Several integrators may be used simultaneously, the disks being of such diameters that the cylinders of the successive apparatus are revolved one, two, three, four, and five times, etc. The instrument being described, having five integrators, gives five pairs of coefficients with one tracing. Two disks are attached to each integrator, so that after one tracing the wire may be slackened and be removed from the lower series of disks d_4 and d_5, Fig. 2, and be wrapped around the upper series, d_9 and d_{10}, causing the integrators to revolve six, seven, eight, nine, and ten times, respec-

tively, for one wave-length, so that with two tracings ten pairs of coefficients are determined.

The relations described remain true as the curve is traced, and the motion of the stylus is continuously resolved into the two rectangular components: one in the direction of the amplitude, producing rolling of the spheres, and the other in the direction of the length of the curve, revolving the integrating cylinders around the several spheres. The integrating cylinders are rolled in such a manner as to add, algebraically, the properly resolved components of the amplitude increments; or, in other words, they perform the process of true, continuous integration as required for the evaluation of the Henrici integrals. The operations of selective analysis and summation are secured by the beautifully related mechanical movements, which proceed so smoothly that they seem almost mysterious. Because of the design and workmanship, which produce continuous movements with the complete elimination of lost motion, remarkable precision is attained, as is illustrated by numerical examples in the latter part of this paper.

The maker of the analyzer has so proportioned and adjusted the sizes of the various parts of the integrators that the readings on the dials are not only *proportional* to the coefficients of the various terms of the Fourier equation, but there are also automatically incorporated in the readings a proportionality factor, the factor π, and the algebraic signs, so that the readings are *exactly equal* to the *amplitudes expressed in millimetres*, without any reduction except for the factor n as mentioned below. The dials indicate 0.1 millimetre directly and 0.01 millimetre by estimation, and they have a capacity for 2000 millimetres before repeating.

The readings of the first set of dials are the amplitudes of the fundamental sine and cosine curves. In the fundamental wave-length there are, of course, two wave-lengths of the second component, and in tracing the curve the second integrator operates over the two waves of this order and at the end its dials show the sum of the amplitudes for the two waves, or twice the amplitude for this component; the third integrator has integrated three wave-lengths, etc. Therefore, at the conclusion of the tracing of the complex curve, any integrator for the nth term indicates n times the corresponding amplitude, which accounts mechanically for the presence of the factor n in the denominator of the Henrici integrals.

The maker has chosen 400 millimetres (about 15¾ inches) for the wave-length; this provides a frame for the instrument which accommodates five integrators, and when the stylus is moved across the wave it gives a movement to the wire which is suitable for putting the integrators into proper action. If the wave-length were less, the disks for the wire would have to be correspondingly smaller, resulting in increased difficulty of revolution of the integrating cylinders, as mentioned in the next section. However, the instrument may be adapted to any specified shorter wave-length by providing new disks for the wire adjusted to have effective circumferences which produce complete revolutions of the integrators in the order of the natural numbers.

When only certain particular components are required, a special set of disks may be provided to evaluate these. For instance, in electric alternating-current waves there are present only odd-numbered terms, and the disks may be arranged for one, three, five, seven, nine, etc., turns of the integrators.

In the development of the theory of the analyzer the general integration contains other parts than the ones so far considered; it is shown that when the integration is taken around a closed curve under conditions such as are involved in the practical operation of the analyzer, these other integrals are eliminated. It is interesting to note that these terms are also present in the mechanical integrations, and that they are automatically eliminated from the readings only at the conclusion of the tracing.

While one wave-length of a complex curve is being traced, the integrating cylinders of any sphere are rotated by larger or smaller amounts, depending upon the instantaneous amplitude. Finally, when the end of the exact wave-length has been reached and each cylinder has been revolved around its sphere an exact integral number of times, the rotation of the cylinder then registered is proportional to the true amplitude of the sine or cosine component whose wave-length is equal to the distance the stylus moved transversely during *one* complete revolution of the cylinder around the sphere; the effects of all other harmonic component curves will have been automatically eliminated from this particular integrator. Further, the sphere of an integrator arranged for evaluating a component of a certain order which in a particular curve has the value zero (as in one of the test curves described later) actually rolls just as much in the amplitude direction as

does any other sphere of the series; the integrating cylinders, revolving around their sphere n times, at several different times in the process of analysis show large readings which are zeroized only at the *end* of the tracing.

When there are *inharmonic* components in the curve, the method of analysis and the instrument here described are not directly applicable. If, however, such a curve is traced, the integrators will indicate the amplitudes of the respective terms of the infinite series of *harmonic* components which may be considered equivalent to the inharmonic components *in so far as the terms of the specified orders are involved.*

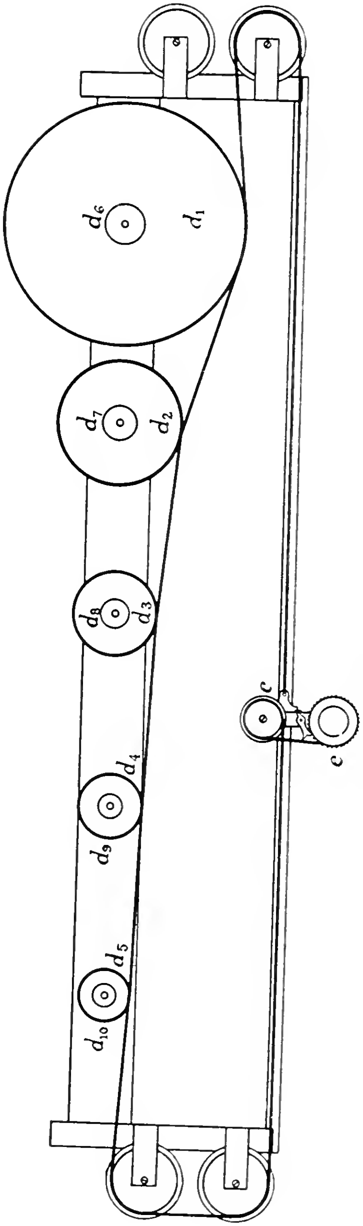
EXTENSION OF THE ANALYZER FOR THIRTY COMPONENTS.

When arrangements were being made for the construction of an analyzer suitable for the investigation of sound waves, Mr. Coradi, the maker, upon being asked whether an instrument could be provided which would determine more than ten components, replied as follows: "The Henrici analyzer has never been arranged for more than ten elements. The diameters of the disks of the eleventh and following elements would become too small to be able to put the integrating apparatus in movement in a correct manner."

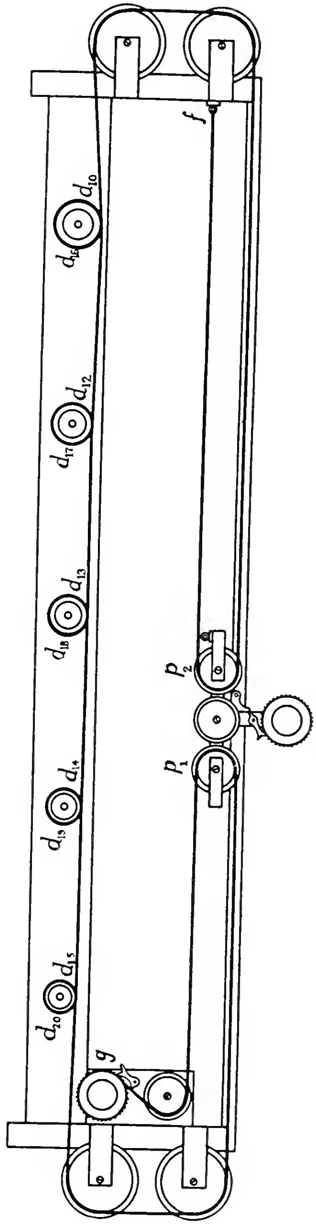
In accordance with this opinion, and because at that time it was thought that sound waves in general would not contain more than ten components, an instrument was purchased arranged for ten components. This analyzer was found sufficient and very satisfactory for the study of curves representing the sounds of the flute. When other sounds, as those of the clarinet and oboe, were investigated, it appeared that at least twenty components must be considered. This necessity led, in 1910,[1] to an addition to the analyzer, extending its range to thirty components. Six years of use, during which thousands of analyses have been made, has shown that the arrangement is very practicable. The new device provides simply for doubling the motion of the wire caused by the travel of the tracing stylus, which provision makes possible the use of larger disks for revolving the integrators, thus obviating the difficulty mentioned by Mr. Coradi.

The scheme of the original wire arrangement is shown in Fig. 5. The wire is attached to the tracing carriage at c, and is threaded around the guide pulleys and around the integrator

FIGS. 5 AND 6.



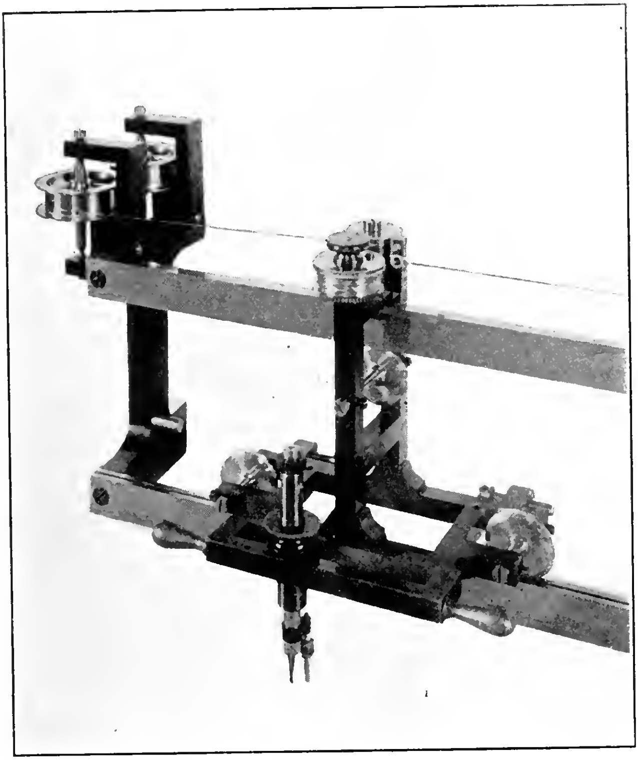
Original scheme for wire for ten components.



New scheme for wire for thirty components.

disks, as shown, and is brought back to the carriage, where it is held taut by winding on the supply drum c, which is held in place by a pawl and ratchet. The effective circumference of the disk d_1 for the first component is 400 millimetres, the wave-length, while the effective circumference of the disk for the tenth component is 40 millimetres, giving a diameter of less than 13 milli-

FIG. 7.



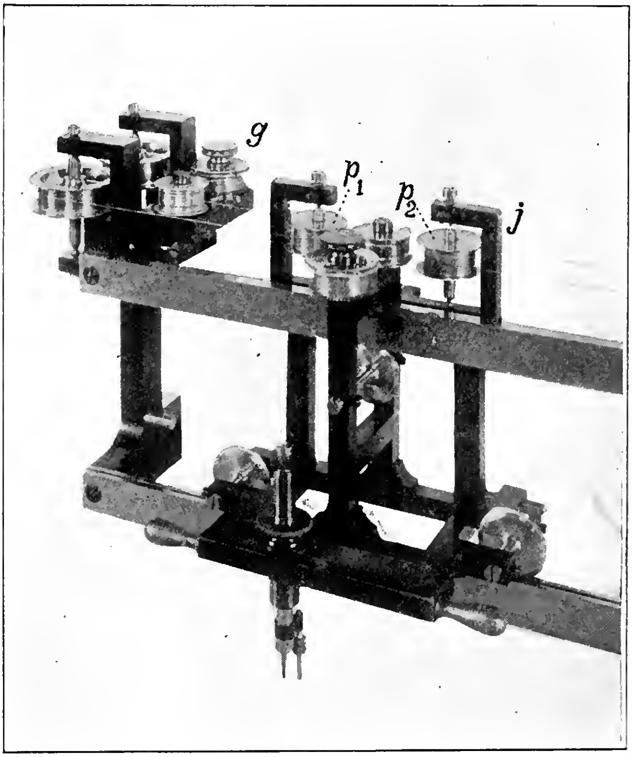
Tracing carriage in original form.

metres. The analyzer is always used in its original form for evaluating the first ten components.

When components of higher order are to be evaluated, a new set of five double-disks is attached to the several integrators, and the wire is arranged according to the new scheme shown in Fig. 6. The wire is attached to the frame at f, and is threaded around a free pulley p_2 on the carriage, around the end pulleys and disks as

shown, and around a second free pulley p_1 on the carriage to the new winding drum at g. Any travel of the carriage now causes a movement of the wire of double the amount. For the eleventh component the effective circumference of the disk d_{11} is $2 \times 400 \div 11 = 72.7$ millimetres, and for the twentieth component it is $2 \times 400 \div 20 = 40$ millimetres, the same as for the tenth component in the original wire scheme.

FIG. 8.



Tracing carriage with new attachments.

A third set of five double-disks has been provided for the components from 21 to 30, the effective circumference of the latter being $2 \times 400 \div 30 = 26.6$ millimetres. When the wire is prepared as described in the next section, the determination of thirty components is entirely practicable. However, since the wire stretches under the increased pull required to revolve the integrators of

higher orders, the last five components are usually determined by two tracings in groups of three and two, respectively, instead of in one group of five.

The nature of the additions to the analyzer to adapt it to the determination of the components of higher orders is shown by a comparison of Figs. 7 and 8: Fig. 7 is a view of the tracing carriage and one end of the frame in the original form, and Fig. 8 is a view of the same parts with the additions. The new parts consist of the rectangular frame *j*, Fig. 8, rigidly attached to the tracing carriage, and the two free pulleys, p_1 and p_2, and of the duplicate guide pulley and winding drum with their support attached to the end of the frame at *g*. There are two new hooks attached to the opposite end of the frame in the position indicated by *f*, Fig. 6. There are also the two new sets of five each of double-disks for the integrators, which are shown on the rack at the back of the view given in Fig. 1.

PREPARATION OF WIRE FOR THE ANALYZER.

The transverse movement of the stylus of the analyzer during the process of tracing a curve is transmitted to the integrators by means of a wire. The wire provided by the maker of the instrument was of copper, silver plated, having a diameter of about 0.27 millimetre (about No. 29 of the Brown & Sharpe wire gauge) and a breaking strength of about 4.5 pounds. Such wire serves fairly well when determining the first ten components, though it is rather soft and subject to stretching, which causes the phases of the revolving integrators to lag slightly. The pull on the wire increases in proportion to the number of revolutions of the disks, and this, added to the rolling action on the wire as it turns the disks, causes so much stretching that the copper wire is not suitable for components above ten.

Experiments have been made with wire of the following materials: Copper, iron, steel, nickel, hard brass, soft brass, German silver, platinoid, and manganin. The steel and hard-drawn brass wires, while free from stretching, were too stiff and springy: where the wire was wrapped around the disks the tendency was to open out and allow slipping. Most of the other wires proved to be too soft and likely to stretch. Soft German silver seemed to be the only suitable material.

The preparation of the wire is as follows: The stock is soft

German silver wire of No. 28 Brown & Sharpe gauge, as obtained from the usual supply dealers, which has a diameter of about 0.31 millimetre. One end of a piece of the wire about 70 inches long is fastened in a vise and the other end is wrapped around the hook of a spring balance. The wire is subjected to a slowly-increasing pull up to about 8 pounds, which is continued for two minutes. This causes a stretch of about 4 inches, after which the wire seems to acquire a permanent set and it may be subjected to an additional pull of one or two pounds without further permanent elongation. This stretching is a kind of tempering process. The wire is next drawn through a steel draw-plate, reducing the diameter to about 0.29 millimetre, and increasing the length to about 84 inches. Finally the wire is drawn through a second and very accurate draw-plate which reduces the diameter to 0.28 millimetre, the length now being about 90 inches; it has a mild spring temper and a breaking strength of about 13 pounds. The wire thus prepared may be used on the analyzer for more than a hundred analyses before it breaks; for the higher-element integrations there is a slight stretch, perhaps amounting to one millimetre, which must be taken up by the winding drum after each such tracing.

A chain, such as the fusee chain of watches, would, no doubt, be very suitable in place of the wire; such chain is used with entire satisfaction in the 32-element harmonic synthesizer described by the author in this JOURNAL for January, 1916. For use with the analyzer a small-sized chain about eight feet long would be required; it is necessary to unthread the chain frequently, and there would be great danger of its becoming kinked and broken. Wire is much more convenient and has been found satisfactory.

THE ANALYZING BOARD.

The analyzer in operation rolls back and forth in the direction of the amplitude of the curve, and it may be placed on any flat surface, as a table, and roll over the paper on which the curve is drawn. To secure a uniform and rectilinear rolling, and to facilitate the operation in general, a special board has been arranged, having for its foundation a drawing-board 30 by 42 inches in size. Two strips of hard wood about one inch wide and one-fourth inch thick are set into the board about an eighth inch, so that the upper surfaces of the strips are about an eighth inch above the surface

of the board; these strips are about 21 inches apart, forming tracks on which the rollers r_1 and r_2, Fig. 1, may run.

A third strip of hard wood is placed against the right edge of the right track, forming a guide for the roller r_2. Two stops are provided near the front edge of the board, against which the analyzer is rolled, setting the instrument as a whole with its axis perpendicular to the tracks. A ledge is placed on the front of the board to prevent the analyzer from accidentally rolling off, and a glass house for the analyzer and attachments is permanently arranged as shown in Fig. 1.

ENLARGING THE CURVES FOR ANALYSIS.

Curves which are to be analyzed with the Henrici analyzer must be drawn to a standard wave-length of exactly 400 millimetres, as has been explained. If a wave is drawn exactly to the wave-length of 200 millimetres, then the integrators for the components 2, 4, 6, etc., of the 400-millimetre series will, of course, give the components 1, 2, 3, etc., for the wave 200 millimetres long, and similarly for other aliquot parts of 400 millimetres.

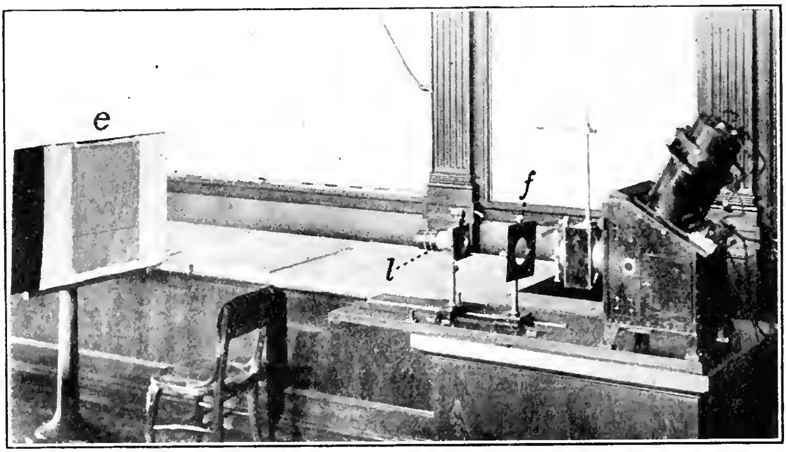
The curves provided by observation are rarely, if ever, of the exact wave-length required, and they must be redrawn. This may be done by plotting numerical data to the proper scale, or the curve may be enlarged with the help of proportional dividers, a pantograph, or other draughting instrument. A photographic camera or enlarging apparatus may be useful. When the original curve has been photographically recorded on a plate or film, a projecting lantern may be the most convenient enlarging arrangement.

The photographs of sound waves obtained with the phonodeik [3] are commonly made on films five inches wide and the wave-lengths vary from 25 millimetres to 100 millimetres. These curves are enlarged with the apparatus shown in Fig. 9, consisting of an optical bench projection apparatus having a lens *l* of large size, with the addition of a special film holder *f* and an easel *e*.

The film holder *f* consists of a frame with an opening covered by a glass plate; this frame is adjustable in two rectangular directions by means of micrometer screws, and is capable of rotation about an axis perpendicular to its own plane. A smaller frame with a glass plate is hinged to the larger one. The film is placed between the two glass plates, and the image of the curve is projected on the easel. The frame is adjusted till the image is in a suitable position for the tracing.

The easel consists of a drawing-board so mounted on a stand that the optical axis of the projection apparatus is perpendicular to the board at its centre. The easel rolls on ball-bearing castors and has a guide resting against a track (the edge of the long table, as shown in the illustration), which permits the easel to be moved forward and backward, the board remaining at all times in the proper relation to the projecting lantern. On the easel are ruled vertical lines 400 millimetres apart and also horizontal lines. The distance of the easel from the film and the position of the lens are adjusted till the image of one wave-length of the curve is exactly 400 millimetres long and is in focus. The wave-length is best

FIG. 9.



Lantern and easel for enlarging curves.

determined by the points where two consecutive waves cross the axis (or any base line) in the same phase; if no base line is given, the sharp crests or troughs, or other definite points of two consecutive waves which are in the same phase, may be used. A piece of paper, 19 by 24 inches in size, is placed on the easel and the wave is traced with a pencil, one wave-length only being required; the axis or base line is drawn, and the curve thus obtained is ready for analysis.

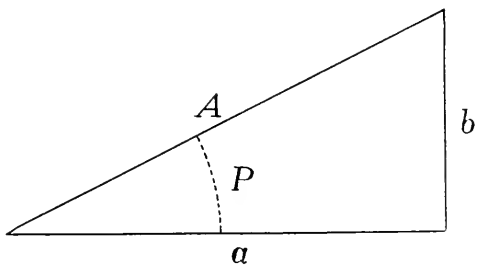
The drawing of all curves to this large scale, on a standard size of paper, facilitates comparison and filing. The harmonic synthesizer[4] used in this work draws curves of the same size, and a

direct comparison of the original and the synthesized curves can always be made. When the operation of enlarging is performed in routine manner, the time required is less than five minutes for each curve.

MACHINE FOR CALCULATING AMPLITUDES AND PHASES.

The equation of a curve as given by harmonic analysis is in the form of a double series of sines and cosines, as explained in the first part of this paper. Another form of the equation, consisting of a series of sines only (or of cosines only), with epochs or phases for the several terms, is more suitable for expressing the results of a physical investigation. The latter form presumably corresponds to the physical phenomena represented, while the former is a mathematical expression resulting from the Fourier method of derivation. It is therefore necessary to reduce the data given by the analyzer to determine the amplitudes and phases of the components of a curve, and this is carried out in accordance with the following principle.[2]

FIG. 10.



Amplitude and phase relations of component and resultant harmonic motions.

The Fourier equation, form III, having on one side a constant term and a series of pairs of sine and cosine terms, may be reduced to the following equivalent form:

$$y = A_0 + A_1 \sin(\theta + P_1) + A_2 \sin(2\theta + P_2) + A_3 \sin(3\theta + P_3) + \ldots \qquad \text{IV}$$

if $a_0 = A_0$ and if each pair of terms, n being the order of the term, is reduced as follows:

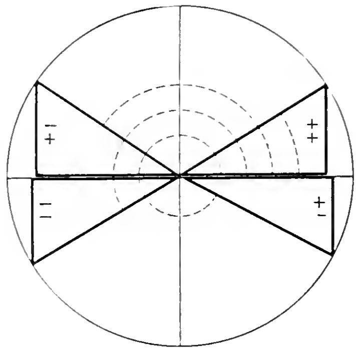
$$a_n \sin n\theta + b_n \cos n\theta = A_n \sin(n\theta + P_n).$$

The relations expressed in this equation are shown by trigonometry to be true when

$$A_n = \sqrt{a^2{}_n + b^2{}_n}, \text{ and } P_n = \tan^{-1}\frac{b_n}{a_n},$$

and these conditions are involved in the relations of the parts of a right triangle. If the base of a triangle is made equal to a and its altitude equal to b, Fig. 10, then the length of the hypothenuse is

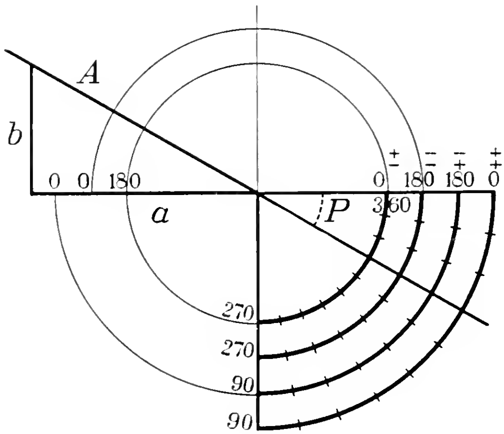
FIG. 11.



Phase angles in four quadrants.

equal to A, as expressed above, and the angle which the hypothenuse makes with the base is equal to P. It is necessary, therefore, to reduce each pair of coefficients given by the analyzer to deter-

FIG. 12.



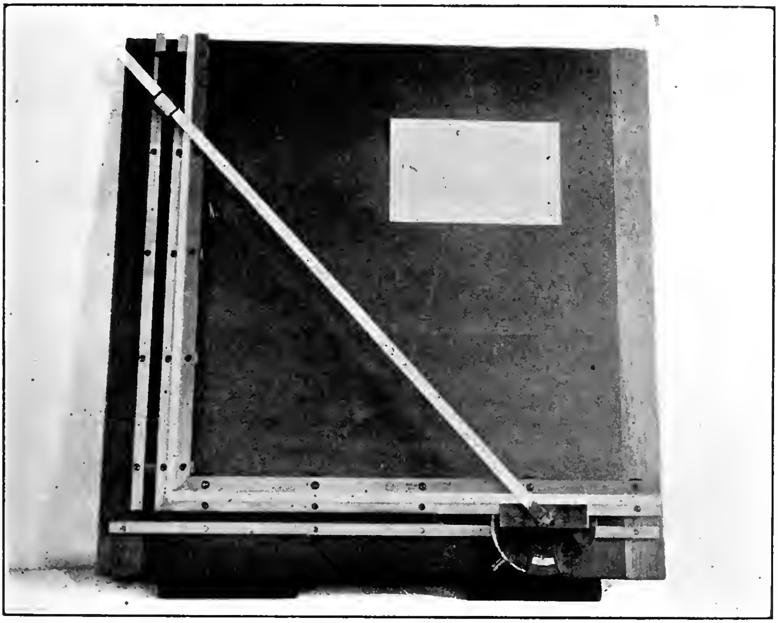
Scheme for measuring phases in one quadrant.

mine A_n and P_n as given by the last two equations. According to the values of n, these equations give the quantity A_1 the amplitude of the first component or fundamental, P_1 its phase, A_2 the amplitude of the second component (octave), P_2 its phase, and so

on. An equivalent expression for the analysis involving cosines only, with phases, can be obtained in a similar manner.

The values of the amplitudes and phases may be obtained by numerical calculation as described in the next section, but it has been found possible to facilitate greatly the reduction by using a machine which has been devised and constructed in our own laboratory. This amplitude-and-phase calculator is essentially a machine for solving right triangles, with the addition of a special angle measurer.

FIG. 13.



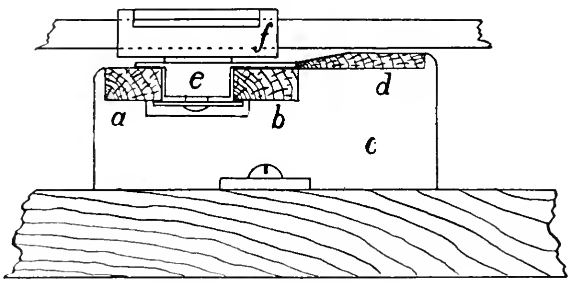
Machine for calculating amplitudes and phases in harmonic analysis.

The analyzer gives directly the numerical values of the coefficients, na_n and nb_n, of the several terms of the general Fourier equation, and each coefficient may have either the positive or the negative sign. For given numerical values of the coefficients there is but one value of the resultant amplitude, $A = \sqrt{a^2 + b^2}$, but the phase $P = \tan^{-1} \frac{b}{a}$ may have any one of four different values, according to the combination of signs, as shown in Fig. 11: For $+a$, $+b$, the angle will have a value between 0° and 90°; for $-a$, $+b$,

its value is between 90° and 180°; for $-a$, $-b$, it lies between 180° and 270°; and for $+a$, $-b$, it is between 270° and 360°. A machine was constructed on the plan of this diagram which measured around a circle; later this was reduced to a quadrant machine with a special angle measurer having four graduations of a quadrant each numbered to correspond to the four possible combinations of algebraic signs, as shown in Fig. 12. Since a single graduated arc may be provided with two sets of numbers, one on each side, two graduations are sufficient, and the machine now in use is so constructed.

The amplitude-and-phase calculator, Fig. 13, the base of which is a drawing-board 24 inches square, consists of two grooves at right angles to each other, provided with linear scales 50 centimetres long, graduated to single millimetres; in the grooves are

FIG. 14.



Cross-section of vertical groove.

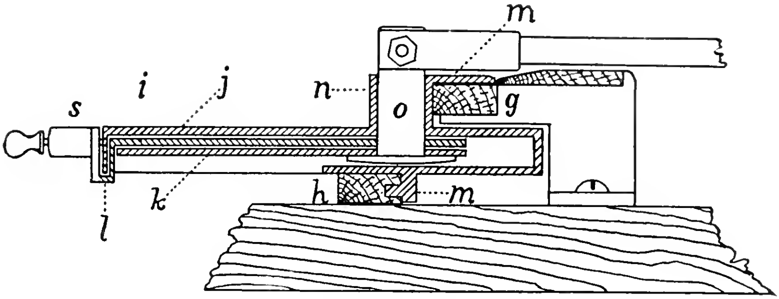
slides carrying the graduated hypothenuse bar, which is 73 centimetres long. One end of the bar is attached to the angle measurer, while the other end slides through a support to which is attached an index for showing the length of the hypothenuse.

The vertical groove, which is about half an inch wide, is made by fastening two strips of hard wood, *a* and *b*, Fig. 14, to brass supports *c*; the bevel-edged graduated scale is shown at *d*, and the slider at *e*. A spring on the under side of the slider gives a smooth and firm movement. The hypothenuse bar slides through the cloth-lined casing *f*, which is pivoted over the centre of the groove.

The zero end of the hypothenuse bar is pivoted over the horizontal groove and is attached to the axis of the graduated quadrant, so that the quadrant is turned through the angle which gives

the phase as indicated by the stationary index lines described below. The two guides, *g* and *h*, Fig. 15, which form the horizontal

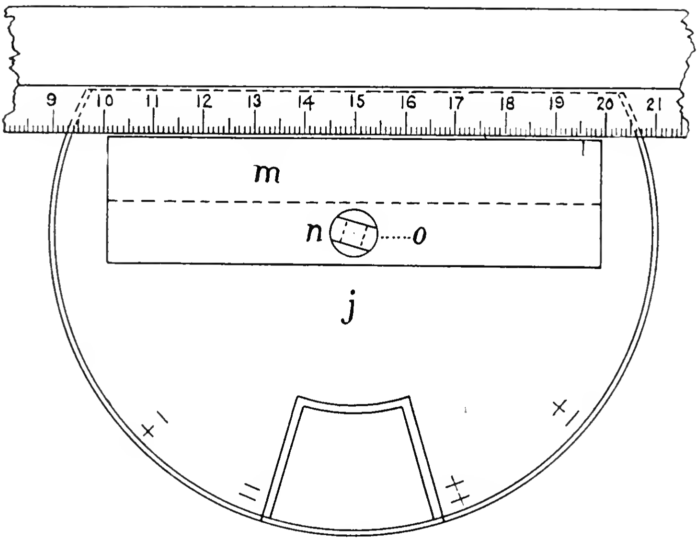
FIG. 15.



Cross-section of angle measurer.

groove, are at different levels to allow the angle measurer *i* to pass over the lower guide.

FIG. 16.

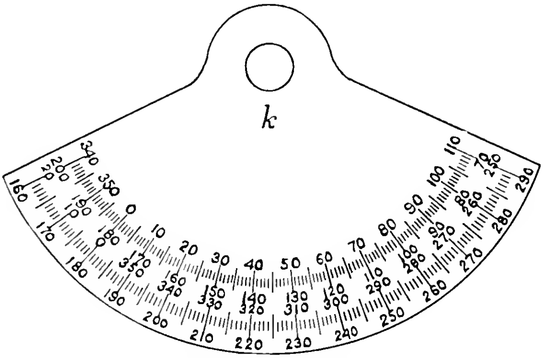


Top plan of angle measurer.

The novel feature of the instrument is the angle measurer, which consists of three parts, the outer casing *j*, Fig. 15, the graduated quadrant *k*, and the index cover *l*. The outer casing *j*, Figs. 15 and 16, carries on its upper and lower faces the guides *m*

which cause it to slide accurately in the groove. This casing also provides a bearing *n* through which passes the stud *o* of the graduated quadrant, so that the centre of the graduation is always

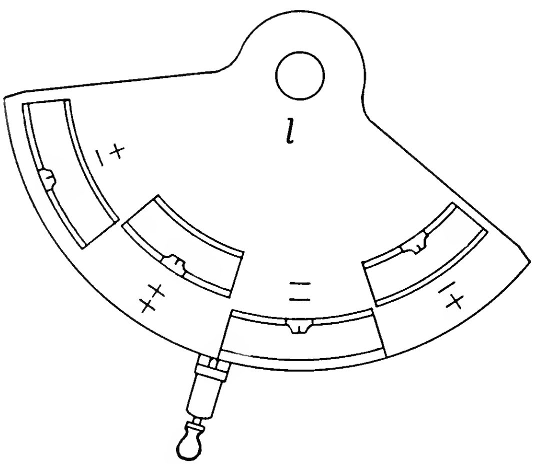
FIG. 17.



The graduated quadrant.

on the centre line of the groove. To the upper end of the stud is attached the zero end of the hypothenuse bar, the nominal zero being over the centre of the horizontal groove.

FIG. 18.



Index-cover for the quadrant.

The graduation of the quadrant, shown in Fig. 17, is in accordance with the scheme of Fig. 12; the graduation is extended a few degrees beyond the quadrant on each side to facilitate reading.

The adjustable index cover, Fig. 18, has four narrow apertures, which, when combined with the aperture in the outer casing as shown in Fig. 16, allow one graduated arc and any one, and only one, of the four sets of numbers to be seen at one time, according to the position of the cover. A spring stop *s*, Figs. 15 and 18, is attached to the cover; there are four positions for this catch, marked for the four possible combinations of the algebraic signs of the coefficients *a and b*: $\substack{+\\+}$, $\pm$, $\mp$, and $=$; when the cover is set, one reads the true phase angle without any reduction.

The graduations for the horizontal and vertical scales begin about 1½ inches from the junction of the grooves, thus bringing the indexes to convenient locations on the sliders. There are several geometrical methods of locating and verifying the several indexes for the linear and circular graduations; when the angle measurer is placed under the vertical groove and is so adjusted that the vertical slider can be moved from one end to the other of its groove with *no change* in the angle of the hypothenuse bar, then the horizontal slider must be in its zero position, and the index must indicate zero on the horizontal scale; the indexes for the hypothenuse bar and for the vertical slider must both show the *same* readings throughout the motion of the slider; the indexes on the cover of the quadrant must show 90° for the $\substack{+\\+}$ and for the $\pm$ positions, and 270° for the $=$ and for the $\mp$ positions. Other similar tests must be made, which will be evident when required.

The linear scales are 50 centimetres long; often the values of *a* and *b* given by the analysis are less than 50 millimetres, in which cases the reduction is carried out by using a centimetre on the machine for a millimetre of the analysis; by reading to single millimetres the result is obtained to tenths of a millimetre. If the values of *a* and *b* are between 50 millimetres and 100 millimetres, it is a simple procedure to use a half of the values for the settings, and to double the hypothenuse reading for the result. If the values of *a* and *b* are still larger, their actual values in millimetres are set off on the machine and the readings are made to tenths of a millimetre. The phases may be read to a tenth of a degree, though usually it is sufficient to read to the nearest half degree.

It is often desirable to state the relative phases of the various components when the phase of the first component is 0°. These

relative phases are obtained by subtracting from the phase of each component n times the value of the phase of the first component (n being the order of the component). A special machine has been devised for transforming the calculated phases into the relative phases when $P_1 = 0°$, but the machine has never been constructed, since the harmonic synthesizer previously referred to gives the relative phases without extra work.[4] In the operation of verifying the analysis of a curve by synthesis, the amplitudes and phases of each component are set up on the synthesizer; it is then only necessary to turn the handle of the synthesizer until the phase dial of the first component indicates 0°, when the direct readings of the phase dials of the other components are the relative phases desired.

CARDS AND CHARTS FOR RECORDS OF ANALYSES.

The comparison and filing of the results of the analyses of many curves is facilitated by using a card form for the record; five such forms have been tried, two of which will be described. Each card, 5 by 8 inches in size, contains the data for ten components; white cards are used for the components from 1 to 10, buff cards for components 11 to 20, and salmon-colored cards for components 21 to 30; blue cards are provided for averages, special data, etc.

When the reduction is to be made by numerical calculation, the form of card shown in Fig. 19 is convenient. The readings of the dials of the analyzer are recorded in the horizontal lines na_n and nb_n; the squares of these numbers are taken from printed tables, such as Crelle's "Rechentafeln," or Barlow's Tables;[6] the sums of the two square numbers for the several components are placed in the line $[nA_n]^2$, and the square roots of these sums, taken from the printed tables, are placed on the next lower line; the latter numbers divided by the respective values of n are the true amplitudes of the harmonic components and are recorded in the line labelled *Amplitude*. The logarithms of the numbers nb_n and na_n are placed in the appropriate lines, and the differences of the logarithms corresponding to each component are the logarithmic tangents of the phase angles, log tan p, and the corresponding angles (taken in the proper quadrants according to the algebraic signs as shown in Fig. 11) are the true phases of the components.

When the calculation of amplitudes and phases is to be made

by machine, as described in the preceding article, the form of card shown in Fig. 20 is more convenient. The readings from the

FIG. 19.

CASE SCHOOL OF APPLIED SCIENCE — DEPARTMENT OF PHYSICS

ANALYSIS OF SOUND-WAVES.

No. 1690 Source Organ Pipe—"Reedless Oboe." Date April 23, 1915

1-10 Tone C_3 Abs. N 260 Purpose analysis

component, n	1	2	3	4	5	6	7	8	9	10
na_n	+ 22.6	+ 99.6	+ 101.1	+ 76.1	+ 44.5	+ 49.1	+ 44.8	+ 24.9	− 11.5	− 7.1
nb_n	+ 94.1	− 87.2	− 42.5	− 7.5	− 26.1	− 10.6	− 3.8	− 66.7	− 36.9	− 21.7
$\|na_n\|^2$	510.76	9920.16	10221.21	5791.21	1980.25	2410.81	2007.04	620.01	132.25	50.41
$\|nb_n\|^2$	8854.81	7603.84	1806.25	56.25	681.21	112.36	14.44	4448.89	1361.61	470.89
$\|nA_n\|^2$	9365.57	17524.00	12027.46	5847.46	2661.46	2523.17	2021.48	5068.90	1493.86	521.30
nA_n	96.8	132.4	109.7	76.5	51.6	50.2	45.0	71.2	38.7	22.8
log nb_n	1.9736	1.9405	1.6284	0.8751	1.4166	1.0253	0.5798	1.8241	1.5670	1.3365
log na_n	1.3541	1.9983	2.0048	1.8814	1.6484	1.6911	1.6513	1.3962	1.0607	0.8513
log tan p	0.6195	9.9422	9.6236	8.9937	9.7682	9.3342	8.9285	0.4279	0.5063	0.4842
p	76°	319°	337°	354°	330°	348.°	355°	290°	252°	252°
Amplitude	96.8	66.2	36.6	19.1	10.3	8.4	6.4	8.9	4.3	2.3
Phase										
Intensity										

Remarks — Sum — Analyzed R.F.K.

Synthesized

Card for record of analysis, for numerical reduction.

FIG. 20.

CASE SCHOOL OF APPLIED SCIENCE — DEPARTMENT OF PHYSICS

ANALYSIS OF SOUND-WAVES

No. 1690 Source Organ Pipe—"Reedless Oboe." Date April 23, 1915

1-10 Tone C_3 Abs. N 260 Purpose analysis

component, n	1	2	3	4	5	6	7	8	9	10
na_n	+ 22.6	+ 99.6	+ 101.1	+ 76.1	+ 44.5	+ 49.1	+ 44.8	+ 24.9	− 11.5	− 7.1
nb_n	+ 94.1	− 87.2	− 42.5	− 7.5	− 26.1	− 10.6	− 3.8	− 66.7	− 36.9	− 21.7
nA_n	96.8	132.3	109.4	76.3	51.6	50.2	45.0	71.1	38.7	22.8
k_n, ( )										
nA_nk_n										
$[nA_nk_n]^2$										
A_n	96.8	66.2	36.5	19.1	10.3	8.4	6.4	8.9	4.3	2.3
P_n	76°	319°	337°	354°	330°	347°	355°	290°	252°	252°
A_nk_n										
Amplitude, %										
Phase										
Intensity, %										

Remarks — Sum — Analyzed R.F.K.

Synthesized

Card for record of analysis, for reduction by machine.

analyzer are recorded as before in the lines labelled na_n and nb_n. The numbers for each component are set off on the amplitude-

and-phase calculator, and the readings of the hypothenuse bar are recorded on the line nA_n, and the phases (the index cover being set to correspond to the signs of a and b in each case) are read directly and recorded on the line P_n. The values of nA_n being divided by the respective values of n give the true amplitudes which are recorded on the line A_n. This completes the analysis. The other data for which provision is made on the card illustrated do not belong to the process of harmonic analysis, but are connected with the correction and reduction of the analyses of sound waves by a particular method which is fully described elsewhere.[3]

The scheme to be adopted for the graphic presentation of the results of a harmonic analysis will depend upon the nature of the phenomena represented. In the investigation of sound waves, the results may be given in terms of the intensity or loudness of the separate components, instead of the amplitude, and the relative values may be shown by plotting on a logarithmic scale of frequencies corresponding to the tones of the musical scale. A description of special charts and plotting scales suitable for such representations has been given in the explanation of the analysis of sound waves just referred to.

PRECISION ATTAINED IN HARMONIC ANALYSIS.

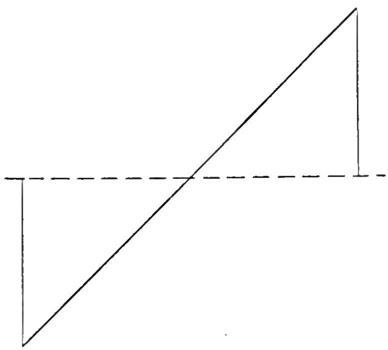
Harmonic analysis is usually applied to curves obtained by plotting observed numbers as coördinates or by graphically recording vibrations with the aid of some form of oscillograph. The forms of such curves can hardly be those of the resultants of a few simple harmonic components. Though the phenomenon represented by a curve is made up of a finite number of periodic components, yet the curve itself may be slightly distorted and will require an infinite series of components, many being of very small magnitude, for its exact reproduction. The methods of analysis by numerical reduction of the measures of the coördinates of a curve have the precision of ordinary graphical methods of investigation; however, many of these methods become much less precise, the higher the order of the component being evaluated.[7, 8]

The Henrici harmonic analyzer probably gives the values of the components with greater precision than it is practicable to obtain by any other method. Numerous tests have been made to determine its precision, and the results of several trials will be explained. Each curve was drawn to the standard size of one

wave-length equal to 400 millimetres, and each was analyzed to thirty components. The numerical results given in the tables are the actual amplitudes in millimetres of the several indicated components, as given by the mechanical analyzer. For Table I the readings were taken to hundredths of a millimetre, while for Table II they were taken only to tenths of a millimetre, a degree of refinement quite sufficient for the tracing of curves drawn on paper. The phases of the components, which are obtained from the readings, are not given at this time, since they are determined with the same order of precision as are the amplitudes.

Table I gives several analyses of each of two test curves. The

FIG. 21.



A test curve, $y = x$.

analyses of the first set are for a straight line inclined at an angle of 45°, $y=x$, Fig. 21, which has an infinite series of components, represented by the Fourier equation (the wave-length being 400),

$$y = \frac{400}{\pi} (\sin x - \tfrac{1}{2} \sin 2x + \tfrac{1}{3} \sin 3x - \ldots).$$

The computed values of the components are given in the column headed *calc;* the columns M – 1 and M – 2 give the values of the components obtained from two analyses made by D. C. M., the tracing being done with great care; the column S – 1 gives the values obtained by D. H. S., when the tracing was done in the usual manner of routine analysis. The average departure of the means of the two analyses by D. C. M. from the true values is 0.022 millimetre, which is one twenty-thousandth of the wave-length, or one ten-thousandth of the amplitude of the original

curve, or one six-thousandth of the amplitude of the fundamental component. The maximum departure in the single analysis by D. H. S. is 0.25 millimetre in the value of the nineteenth component.

TABLE I

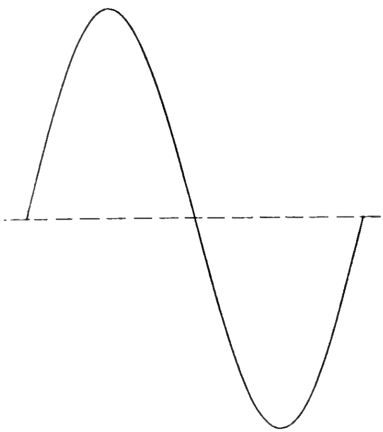
Analyses of Special Test Curves.

Comp.	Amplitudes of components in millimetres						
	Straight line, $y = x$				Sine curve, $y = \sin x$		
n	Calc.	M – 1	M – 2	S – 1	H – 1	H – 2	H – 3
1	127.32	127.30	127.30	126.90	250.03	250.27	250.03
2	63.66	63.55	63.60	63.35	0.97	0.94	0.71
3	42.44	42.47	42.50	42.37	0.69	0.56	0.72
4	31.83	31.85	31.82	31.75	0.27	0.28	0.28
5	25.46	25.50	25.46	25.46	0.19	0.22	0.22
6	21.22	21.17	21.17	21.24	0.31	0.29	0.20
7	18.19	18.16	18.14	18.14	0.20	0.12	0.10
8	15.91	15.94	15.97	15.90	0.08	0.11	0.05
9	14.15	14.12	14.15	14.14	0.20	0.03	0.11
10	12.73	12.75	12.70	12.73	0.05	0.11	0.04
11	11.57	11.60	11.56	11.65	0.18	0.10	0.13
12	10.61	10.64	10.67	10.50	0.18	0.10	0.09
13	9.79	9.81	9.80	9.73	0.04	0.08	0.04
14	9.09	9.09	9.17	9.00	0.12	0.14	0.09
15	8.49	8.50	8.49	8.45	0.14	0.07	0.11
16	7.96	7.91	7.97	8.02	0.12	0.05	0.05
17	7.49	7.51	7.40	7.44	0.13	0.04	0.08
18	7.07	7.10	7.02	6.93	0.04	0.04	0.03
19	6.70	6.71	6.70	6.95	0.19	0.02	0.11
20	6.37	6.43	6.41	6.21	0.06	0.09	0.10
21	6.06	6.04	6.06	6.09	0.15	0.06	0.10
22	5.79	5.81	5.78	5.81	0.06	0.14	0.12
23	5.54	5.53	5.46	5.48	0.10	0.06	0.09
24	5.30	5.23	5.23	5.36	0.09	0.08	0.18
25	5.09	5.10	5.07	5.17	0.11	0.08	0.04
26	4.90	4.91	4.90	4.99	0.03	0.03	0.10
27	4.72	4.78	4.73	4.70	0.07	0.07	0.13
28	4.55	4.61	4.52	4.40	0.03	0.01	0.11
29	4.39	4.41	4.39	4.36	0.11	0.10	0.10
30	4.24	4.25	4.26	4.12	0.04	0.10	0.18

The analyses of the second set given in Table I are for a simple sine curve, Fig. 22, $y = \sin x$, three successive analyses, all made by R. F. H., being shown in the columns marked H – 1,

H – 2, and H – 3. This curve which was drawn by the harmonic synthesizer was presumed to have but one component, a fundamental of an amplitude of 250 millimetres. While all the higher components have very small values, components two and three have values which are not due to inaccuracies in reading. It is probable that these small readings correspond to real components existing in the curve; a very slight distortion might introduce an infinite series of very small components. The reality of the components is indicated by the fact that the successive analyses give values differing but little from each other. The average of all the readings of the three analyses for all components above the sixth

FIG. 22.



A test curve, $y = \sin x$.

is 0.09 millimetre, while the largest single value is 0.2 millimetre. The latter quantity is less than the width of the line which represents the curve. As already mentioned, the rolling spheres of the integrators for these higher components actually roll just as much in the amplitude direction as does the sphere for the first component, which has an amplitude of 250 millimetres; and the integrating cylinders, revolving around their spheres, at several different times in the process of analyzing the curve show large readings, which readings for a zero component are zeroized only at the end of the tracing; therefore it is not surprising that the final readings differ from zero by one- or two-tenths of a millimetre.

Table II gives three values of the analyses of each of two curves of unknown composition, the photographed curves of the sound waves from a clarinet, Fig. 23, and from an oboe, Fig. 24.

TABLE II

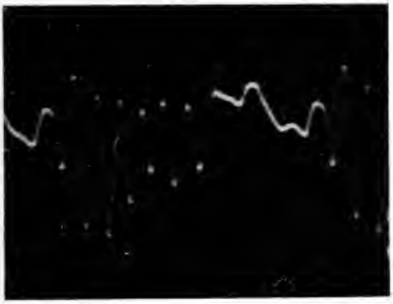
Analyses of Sound Waves

Comp.	Amplitudes of components in millimetres					
	Clarinet curve No. 85			Oboe curve No. 81		
n	M – 1	M – 2	S – 1	M – 1	M – 2	S – 1
1	30.3	30.3	30.7	90.5	90.5	90.9
2	7.2	7.2	6.9	77.5	77.1	76.8
3	20.8	20.6	20.8	37.8	37.8	37.4
4	2.2	2.2	2.0	31.2	31.2	31.9
5	1.1	1.3	1.5	42.6	43.1	42.7
6	5.8	5.8	6.0	12.9	12.4	12.6
7	7.1	7.2	6.6	46.3	46.9	46.6
8	6.9	7.2	7.3	34.6	34.5	34.5
9	17.0	16.8	17.2	14.9	15.5	15.2
10	11.8	11.6	11.9	6.2	5.9	6.1
11	23.8	24.1	23.2	0.7	0.7	0.7
12	34.9	35.3	35.2	3.3	3.7	3.5
13	20.0	20.3	20.8	5.0	5.1	5.0
14	8.9	8.8	9.6	0.6	1.1	0.8
15	2.2	2.2	2.7	4.3	4.5	4.4
16	1.2	1.0	0.4	3.9	4.0	3.9
17	1.4	1.4	0.9	2.9	2.9	2.9
18	0.8	1.0	0.9	1.5	1.4	1.5
19	2.4	2.4	2.3	0.8	0.3	0.6
20	2.3	2.1	2.3	2.5	2.6	2.5
21	3.7	3.5	3.7	2.4	2.4	2.5
22	3.5	3.2	4.1	0.4	0.4	0.4
23	3.1	2.8	2.0	1.7	1.5	1.6
24	7.3	7.0	6.3	1.6	1.1	1.3
25	5.3	5.4	4.5	0.8	0.5	0.7
26	2.8	2.5	2.7	0.3	0.3	0.3
27	0.7	0.8	0.9	0.5	0.5	0.5
28	0.2	0.2	0.2	0.9	0.9	0.9
29	1.0	1.1	1.0	0.8	0.7	0.8
30	0.3	0.3	0.3	0.5	0.2	0.3

These analyses were all made with only the ordinary care of routine work. The variation is of the order of 0.2 millimetre, which is less than the width of the line of the curve.

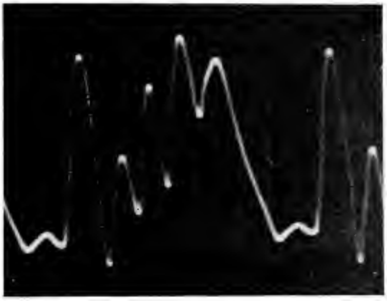
The conclusion is that the Henrici harmonic analyzer possesses an inherent accuracy much greater than can be taken advantage of in graphic work. The results are always accurate to a fraction of the width of the line representing the curve, and this precision

FIG. 23.



Photograph of the sound wave from a clarinet.

FIG. 24.



Photograph of the sound wave from an oboe.

is maintained uniformly for all the components, even to the thirtieth. If a curve could be traced exactly, the analyzer would undoubtedly give results of high precision, equalling one part in five thousand or more. Such accuracy is not approached by other

FIG. 25.

Photograph of the sound wave from an organ pipe.

instruments or methods of easy calculation with which the writer is acquainted.

Table III gives the results of three analyses, by different methods, of the same curve, the sound wave from an organ pipe,

Fig. 25: the first is purely mechanical (time required, thirteen minutes), the second is by the complete numerical reduction from thirty-six measured ordinates (time required, ten hours), and the third is the reduction from eighteen measured ordinates by means of a prepared schedule (time required for eight components, three hours).

TABLE III

Analyses of Organ-pipe Curve No. 1690 by Three Methods.

Amplitudes of components in millimetres			
Comp. n	Henrici analyzer	Steinmetz arithmetical	Grover schedule
1	96.8	97.0	96.6
2	66.2	66.0	66.5
3	36.5	36.7	37.2
4	19.1	19.0	19.9
5	10.3	10.4	13.6
6	8.4	8.9	9.7
7	6.4	7.2	8.4
8	8.9	9.0	12.0
9	4.3	4.1	
10	2.3	3.1	

TIME EFFICIENCY OF ANALYSIS BY MACHINE.

The analytical investigation of sound waves by the author has required the performance of hundreds of thousands of numerical operations, and an effort has been made to determine the most efficient methods of reduction. Some of the results of this study are as follows:

Addition.—The additions mostly required in the work referred to are of groups of ten (or twenty) numbers, each number having from one to four digits. A large number of such groups were added by two different computers, mentally and with each of three different machines. A typical result only will be given. R. F. H. added ten columns of ten numbers each mentally in 515 seconds, while the same additions with two machines required 834 seconds and 821 seconds respectively: L. W. S. required 510 seconds for the mental operations and 930 seconds for the machine additions. The fact that some of the machines recorded the numbers added is of no value in this work. The errors are few, and were no more and no less frequent in the mental operations than in the machine work.

Multiplication.—The multiplication of two numbers of from three to five digits each was performed with Crelle's "Rechentafeln" and with a Brunsviga calculating machine by R. F. H. With the tables 163 products were secured per hour, and with the machine 175 products per hour.

Division.—The only operation of division required in our work is the finding of the percentages of each of ten or twenty components, the sum of the components being given. This is carried out with a 20-inch slide rule, requiring three minutes to determine the percentages of twenty components.

Squares.—The squares of numbers of three digits are most easily taken from Crelle's "Rechentafeln," which, on two opposite pages, gives the squares of all numbers of from one to three figures.

Enlarging Curves.—The redrawing of a photographed curve to the standard size required for analysis, having a wave-length of 400 millimetres, requires, on the average, 4.1 minutes with the apparatus described.

Amplitudes and Phases.—The reduction of the coefficients obtained with the Henrici analyzer to obtain the amplitudes and phases of the components of a curve, by the numerical method represented by the card form shown in Fig. 19, using Crelle's "Rechentafeln" for the squares and square-roots, and four-place logarithm tables for the phases, requires twenty-eight minutes for ten components. The same reduction is made with the machine shown in Fig. 12, according to the card form of Fig. 20, in five minutes.

Synthesis.—The synthesis of a curve of ten components, forming a complete verification of the analysis, can be performed by the machine previously described, for ten components, in five minutes; for thirty components, in twelve minutes.

Analysis.—With the Henrici analyzer one tracing of a curve gives the data for five components; the time required for tracing a curve twice, including the changing of the wire, and for reading and recording the results, for ten components is ten minutes. Since an analysis is considered complete only when the data have been reduced to give the amplitudes and phases, the time for an analysis is then about fifteen minutes. As described in "The Science of Musical Sounds," pp. 122 and 136, the analysis and reduction of a certain curve by machine required thirteen minutes;

the analysis of the same curve by a method described by Steinmetz [2] required ten hours for ten components; the analysis with the help of prepared tabular forms as described by Grover [8] required three hours for the determination of eight components, the largest number for which a form was available.

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[8] Harmonic analysis, using prepared schedules: C. Runge, *Zeitschrift für Mathematik und Physik*, **48**, 443–456 (1903); **52**, 117–123 (1905). F. W. Grover, *Bulletin of the Bureau of Standards*, **9**, pp. 567–646 (1913). H. O. Taylor, *Physical Review*, **6**, 303–311 (1915).

THE USE OF POWDERED COAL IN METALLURGICAL PROCESSES: A DISCUSSION OF THE ENGINEERING PRINCIPLES INVOLVED.*

BY

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THE process of burning powdered coal is the best method by which to obtain perfect chemical combination of the air and coal, and by which the highest degree of perfection in combustion may be obtained if properly applied. There is no other fuel so responsive to correct application. The greatest precision is required in its control, and it may be said that, so far as the art of burning powdered coal has been developed, it is perhaps in too great a measure dependent upon the human equation.

The essential features necessary for success in the use of this fuel for metallurgical furnaces are:

First.—That the coal should have a high volatile content—low in ash.

Second.—That, after pulverizing, the moisture in the fuel should not exceed three-fourths of one per cent.

Third.—That it be pulverized so that at least 95 per cent. will pass through a 100-mesh sieve and over 83 per cent. through a 200-mesh sieve.

Fourth.—That the delivery of the coal to the furnace be uniformly controlled, regardless of the quantity required.

Fifth.—That it be delivered to the furnace in a thoroughly atomized state, and that combustion be completed while the coal is in suspension.

Sixth.—That in the application of this fuel the personal equation be eliminated as far as possible.

The use of powdered coal as a fuel necessitates the installation of an efficient crushing, drying, pulverizing, conveying, and distributing equipment and, in addition, ample storage room for coarse coal.

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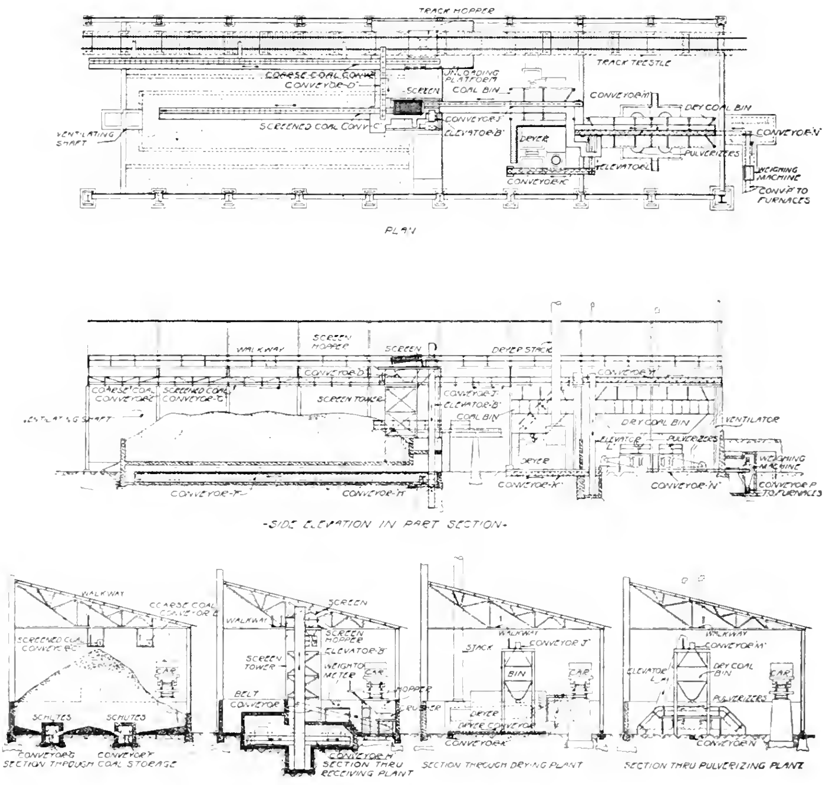
Fig. 1 shows a plan, side elevation in part section, and four cross-sections of a coarse coal storage, drying, pulverizing, and conveying equipment.

The incoming coal is brought up an inclined plane to the elevated trestle and discharged from cars of the bottom-dump type into the track hopper. A pusher feed located on the bottom

FIG. 1.



of the track hopper controls the flow of coal to the crusher, the crushed coal falling by gravity on to belt conveyor "A," which discharges into the shoe of elevator "B." Belt conveyor "A" is fitted with a Merrick weightometer, which affords an accurate check on the tonnage received. The nature of the coal received determines the operation of the crushing rolls. In the case of slack coal, the crusher rolls are set apart and the coal falls

by gravity from the pusher feed through the crusher to the belt conveyor "A."

The discharge from elevator "B" is so arranged that it can either be spouted direct to conveyor "J," which feeds the coal storage bin over the dryer, or to the revolving screen. All coal placed in storage is spouted from elevator "B" to the revolving screen, which sizes it to cubes of 1 inch and under, the finer coal dropping into the hopper below the screen, thence on to flight conveyor "C," which distributes the coal in the storage. The coarser coal is discharged from the screen to the cross flight conveyor "D," thence on to the flight conveyor "E," from which point it is spouted to cars for use elsewhere.

Under the storage pile two concrete reclaiming tunnels are provided, each equipped with a flight conveyor. Chutes equipped with tunnel gates are spaced at proper intervals on each side of these tunnels, through which the coal from the storage pile travels by gravity on to the flight conveyor "F" or "G," and discharges into the reversible flight conveyor "H," which in turn discharges into elevator "B," from which point it is elevated and spouted to conveyor "J," distributing the fuel in the storage bin over the dryer.

A suitable feeding mechanism is located in the bottom of the coal storage bin over the dryer, which feeds the coal at a uniform rate into the upper end of a rotary dryer. The coal passes through the dryer, which removes the moisture, and is then discharged into the dust-proof screw conveyor "K," thence into the dust-proof elevator "L," thence to the dust-proof screw conveyor "M," which distributes the dried coal into the dust-proof storage bin over the pulverizers.

From the dust-proof dried-coal storage bin the coal travels by gravity to the feeding mechanism on the pulverizing mills. The powdered coal is discharged from the pulverizers into the dust-proof screw conveyor "N," from which point it is conveyed to the weighing machine, which automatically registers the weight of fuel pulverized. A by-pass connecting conveyors "N" and "P" provides a cut-out for the weighing machine and adjustments, and repairs can be made to this unit without shutting down the system. The weighing machine discharges into the dust-proof screw conveyor "P" connecting with the distributing system.

FIG. 2.

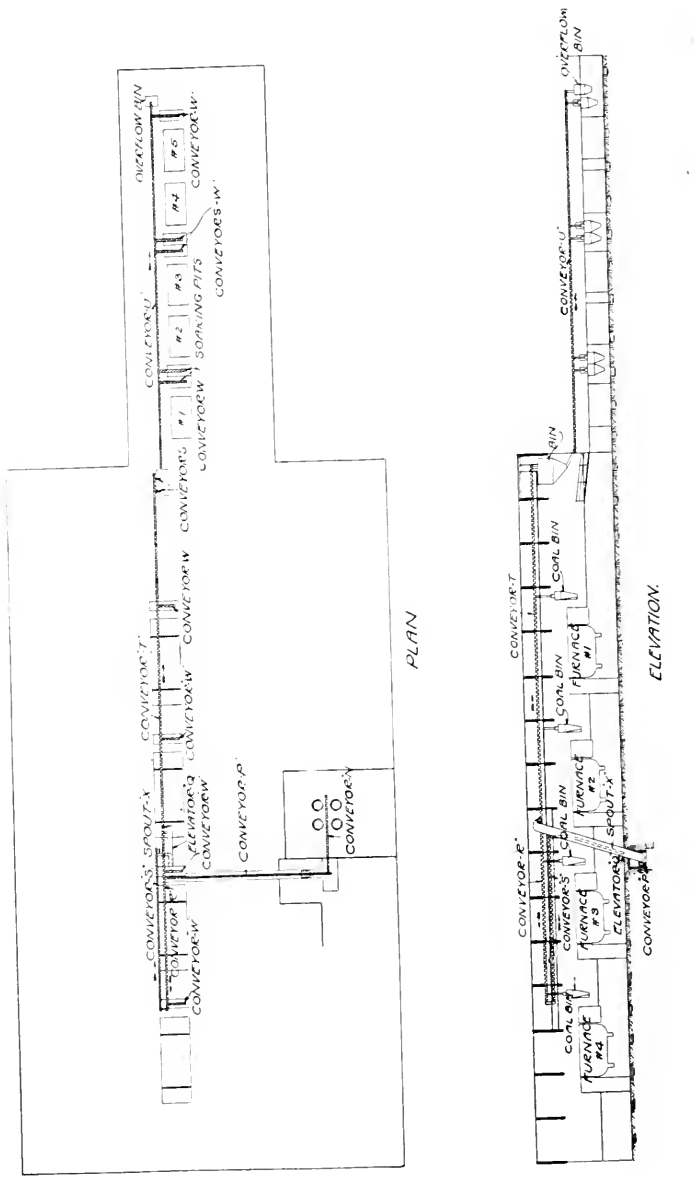


Fig. 2 shows a plan and elevation of a powdered-coal distributing system. This equipment furnishes powdered coal to four 50-ton open-hearth furnaces and five double soaking pits.

The dust-proof screw conveyor "P" carries the coal to the dust-proof elevator "Q," which discharges into the dust-proof screw conveyors "R" and "T." The powdered coal in conveyor "R" travels in the direction as indicated by the arrow and feeds the coal storage bins located at Furnaces Nos. 3 and 4. Any coal left in this conveyor after passing the coal storage bin at Furnace No. 4 is discharged at the end of the line into the dust-proof screw conveyor "S" below, which returns the surplus coal to the spout "X," and thence by gravity to the shoe of elevator "Q." With this arrangement there is little possibility of the conveying system being choked through careless operation. The powdered coal fed to conveyor "T" travels in the direction as indicated by the arrow and feeds the coal storage bins located at Furnaces Nos. 2 and 1. The storage bin at the end of the line into which this conveyor discharges eliminates the possibility of stalling the conveyor. In addition to feeding coal to the storage bins at Furnaces Nos. 2 and 1, all the coal used by the soaking pits is conveyed over this line. The dust-proof screw conveyor "U" feeds the powdered coal to the five storage bins located at each of the five double soaking pits. Each storage bin at the open-hearth furnaces and soaking pits is equipped with an automatic weighing machine, recording the weight of coal fed to each furnace, and the coal from these scales is distributed in the storage bins by the dust-proof screw conveyors "W."

From the time the coal leaves the dryer to its delivery in the furnace the whole system between these points should be dust-proof and the greatest care should be taken to prevent leakage. This should be guarded against systematically, as leaks, however small, may permit the surrounding air in the room to become impregnated with coal dust to such an extent that a serious explosion may result.

Coal, after pulverizing, should be handled in bulk. All types of aërial propulsion and transfer in the form of dust clouds should be avoided, for the reason that accidental ignition may at any time wreck the whole system.

Screw conveyors and bucket elevators equipped with dust-proof casings are best adapted to handling powdered coal in bulk. Screw conveyors of 9 inches and 12 inches diameter should not exceed 250 and 300 feet respectively, if the best results are to be expected. Where transmission lines of greater length are necessary they should be divided.

The storage of powdered coal in large or small quantities for any length of time is not advisable, owing to its tendency to fire, collect moisture, and pack.

Powdered coal in storage, containing about three-quarters of one per cent. moisture and one per cent. sulphur, will invariably fire within six days. If the moisture be increased to over one per cent. and the sulphur to four or five per cent., spontaneous combustion may occur within twenty-four hours. Probably the temperature at which powdered coal is delivered to the storage bin, and the sulphur content of the coal, influence the rate of spontaneous combustion rather than moisture.

Owing to the hygroscopic nature of dried powdered coal, long storage is not desirable.

In its normal state powdered coal is light and fluffy; after forty-eight hours' standing in storage, however, the physical arrangement of the particles produces a dense packed mass. So dense does the fuel become that one's fingers cannot make an impression even one-half inch deep. To meet ideal conditions, powdered coal should be kept in motion.

With properly designed machinery and storage bins, having twelve hours' supply placed at each furnace, the coal may be kept in motion and repairs and adjustments made before the supply becomes exhausted.

FUEL.

Low-grade bituminous coals, anthracite, lignites, and even coke breeze in a powdered form, can be burned with good results, certain types of heating furnaces now being operated with such fuels.

It should be understood that the first cost of fuel used is not the correct index by which to judge of economy when fuel must be prepared and pulverized.

Low-grade bituminous coals, being high in non-combustible content, occasion an inordinately high pulverization cost, as compared to high-grade bituminous coals. Equally, anthracite coals of highest first cost not only add to the pulverization cost on account of their hardness, but, although having little non-combustible content, their economy in actual use is not to be compared to that of the best bituminous coals, because of their high fixed carbon content, resulting in much slower ignition.

One of the disturbing factors in the use of powdered coal

is that of the large accumulations of ash deposited within the furnace, only a small proportion escaping through the stack. When using even a good grade of coal, ash will accumulate rapidly, and therefore fuel of low ash content is always most to be desired.

In obtaining the best economy in any particular case there must be a blending of plant location with the prices of available fuels of varied grades and of the results of tests conducted under operation.

Slack coal is preferable to other forms: it costs less, requires less power for pulverizing, owing to its fine state, and materially increases the capacity of the pulverizer.

While the presence of sulphur in small quantities in powdered coal has no ill effect in heating and annealing furnaces, it should be given careful attention when used in the reduction and refining of metals or ores.

Generally speaking, therefore, the fuel available for burning in metallurgical furnaces has a restricted range both as to species and quality. Only the best bituminous coals, high in volatile content and low in both sulphur and ash, are desirable.

Coal used in heating and puddling furnaces should closely approximate the following analysis:

Volatile matter	Not under	30.00
Fixed carbon	Not under	50.00
Moisture	Not over	1.25
Ash	Not over	9.50
Sulphur	Not over	1.00

In open-hearth furnaces a still better grade is desirable, a suitable analysis being as follows:

Volatile matter	Not under	36.00
Fixed carbon	Not under	52.00
Moisture	Not over	1.25
Ash	Not over	6.00
Sulphur	Not over	1.00

DRYING.

The dryer generally used for the purpose of preparing coal before pulverizing is of the revolving cylinder type, provided with an external furnace, usually equipped with an automatic stoking device.

The fuel consumption of the dryer will vary with reference to

the amount of moisture to be removed. In drying coal containing about one and one-quarter per cent. moisture, to be dried to one-half of one per cent. or less, the fuel consumption should not exceed 26 pounds per ton.

The power consumption for operating the complete drying unit, which includes the power consumed by the coal-feeding mechanism, the dust fan, the stoking device, and in revolving the dryer cylinder for a ten-ton capacity dryer, figures about one and one-half kilowatt-hours per ton of dried coal.

In the operation of the dryer care should be taken to avoid overheating, in order not to fire the coal or to drive off part of the volatile content.

If the moisture is allowed to exceed three-fourths of one per cent., operating troubles result, and these become intensified the higher the percentage of moisture.

Moist coal reduces the capacity of screen-type pulverizers, as moist coal will clog the screens. Also, the moisture in the coal governs in a large measure the tendency to pack and to arch in the storage bins, causing an intermittent flow of coal to the feeding device and the consequent loss of the one most essential factor; namely, uniform feed to the furnace.

It is easier to dry coal to one-half per cent. moisture or less than it is to maintain it in this state. This is explained by the fact that the moisture driven off from the coal in the process of drying saturates the hot air contained in the dryer cylinder. In this highly saturated condition the air follows the dried coal through the dust-proof conveying system to the enclosed storage bin. As the coal and air cool, moisture is precipitated and the volume of the air diminished, with the result that more warm saturated air is drawn from the dryer. These conditions, obviously, meet the requirements of a still of fair proportion.

The precipitation of moisture resulting from the cooling process of the coal and air may be almost entirely overcome by placing ventilating shafts on the storage bin and the high points of the conveying system connected with the outside air. Each shaft should be equipped with a ventilator of approved type, and proper provision should be made to collect and deflect any condensation in the ventilating shafts, so as to prevent its return.

It is thus evident that in the process of drying, through the medium of heat, a small quantity of the expelled moisture will

find its way back in the coal after cooling. For this reason it is good practice to gauge the dryer so that the resultant product leaving the dryer will contain less than one-half of one per cent. moisture.

PULVERIZING.

In order to obtain high efficiency of combustion, powdered coal should be reduced to a fineness so that 95 per cent. will pass a sieve of 100 meshes to the linear inch and so that 83 per cent. will pass a sieve of 200 meshes to the linear inch. Greater degrees of fineness will undoubtedly produce higher efficiency of combustion.

Machinery for pulverizing is adapted to two systems of coal-dust burning. In one system the pulverizer has a capacity sufficient for one furnace and delivers the powdered fuel directly into the burner without intermediate storage. In the other system the pulverizers have a large capacity, and one unit will pulverize enough coal to operate several furnaces, the distributing system being so arranged that the powdered coal is conveyed to storage bins, preferably near the furnaces.

There are a number of designs of pulverizing machines of merit on the market, but only one will be briefly described in this paper.

One of the pulverizers largely used is the Fuller-Lehigh mill. The material to be reduced is fed to the feeder hopper of the mill from an overhead bin by gravity. The feeder is mounted on top of the mill and has a range of three speeds; in addition, the feeder hopper is provided with a slide, which permits the operator to increase or decrease the amount of material entering.

The pulverizing mechanism consists of four unattached steel balls, which are propelled around the grinding ring by means of pushers attached to the mill shaft. Above the grinding ring and the balls is a fan having two rows of blades, one above the other. The lower set of fan blades lifts the finished product from the pulverizing zone into the chamber above the grinding ring, where it is held in suspension by means of the fan action of the upper row of blades until it is floated out through the screen, which completely encircles the separating chamber. The finished product is discharged through a spout which may be placed at any one of four quarters of the mill. All material discharged from the mill is finished product and requires no subsequent screening.

These machines are eminently suited for the production of finely ground material. They have a high mechanical efficiency and are economical in cost of installation, operation, and maintenance.

In the process of pulverizing, a large part of the heat generated is absorbed by the coal and contained air. The temperature which they attain is high enough to expel part of the moisture in the coal, while the air is of a sufficiently high temperature to establish satisfactory saturation.

The coal and air cool off in their course through the dust-proof distributing system to the enclosed storage bins, and a similar condition exists as in the case of dried coal as heretofore referred to. Similar attention must be given to ventilation; otherwise it would be a common occurrence to find water dripping from the bottom of storage bins ten or twelve hours after filling.

The pulverizers, after being shut down, sweat in cooling, and proper ventilation is the only preventive.

The power consumption of the pulverizer will vary according to quantity of output and degree of fineness of the finished product. Pulverizing mills of the type described, having a capacity of about four and one-half tons per hour, pulverizing to a fineness so that 95 per cent. will pass through a 100-mesh sieve and 83 per cent. through a 200-mesh sieve, will consume about 10.5 kilowatts per hour per ton of product.

In a plant having an average output of 200 tons of powdered coal per day the cost is as follows:

	Per gross ton of coal produced
Fuel for dryer	$0.030
Repairs, buildings, machinery, and equipment	.200
Labor	.150
Power and light	.215
Supplies	.005
	$0.600

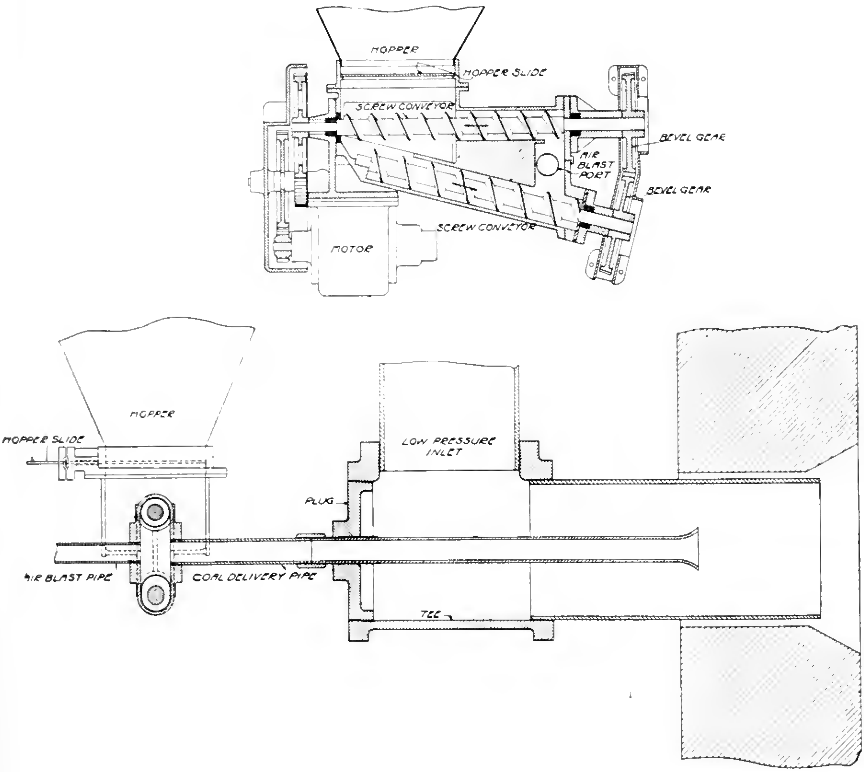
The above figures include all costs, from the receipt of the coal in the cars to its delivery in a powdered state in the furnace. No allowance has been made for overhead and depreciation.

Shrinkage in the coal becomes a prominent factor, and must not be lost sight of. It may vary from 150 pounds to 270 pounds per gross ton.

FEEDERS AND BURNERS.

Powdered-coal feeders are of two kinds—one type consisting of a mechanically operated screw or flight conveyor having a variable feed, the other type consisting of a siphon, through which the fuel is fed by the medium of compressed air, the feed being regulated by the air-pressure.

FIG. 3.



Burners for powdered fuel are operated under either low or high pressure. Low-pressure burners are used with an air blast varying from two ounces to eight ounces. High-pressure burners are used with compressed air varying from forty to one hundred pounds pressure.

Fig. 3 illustrates a sectional elevation of a mechanically operated low-pressure feeding apparatus for coal dust, also a sectional

view of the feeder taken across the air-blast ports, showing the method of its connection with the burner.

By referring to the sectional elevation it will be noted that from the hopper the horizontal conveyor screw delivers a stream of coal in the direction of the arrow mark, which falls as a continuous shower past the air-blast ports, and is picked up by a cross-stream of air, which delivers the mixture through the coal-delivery pipe to the burner.

The quantity of fuel delivered by the conveyor screw is regulated by varying the speed of rotation, which in this case is obtained through a direct connected variable speed motor. The amount of fuel taken up by the cross-current of air will vary with the pressure of the air blast, which is controlled by a suitable valve placed in the blast line. Any excess fuel escaping the feeding action of the air blast is automatically returned to the hopper by the lower inclined conveyor screw.

The coal-delivery pipe discharges its mixture into the burner, the low-pressure inlet pipe furnishing the necessary additional air for combustion, and the resultant mixture is discharged into the furnace.

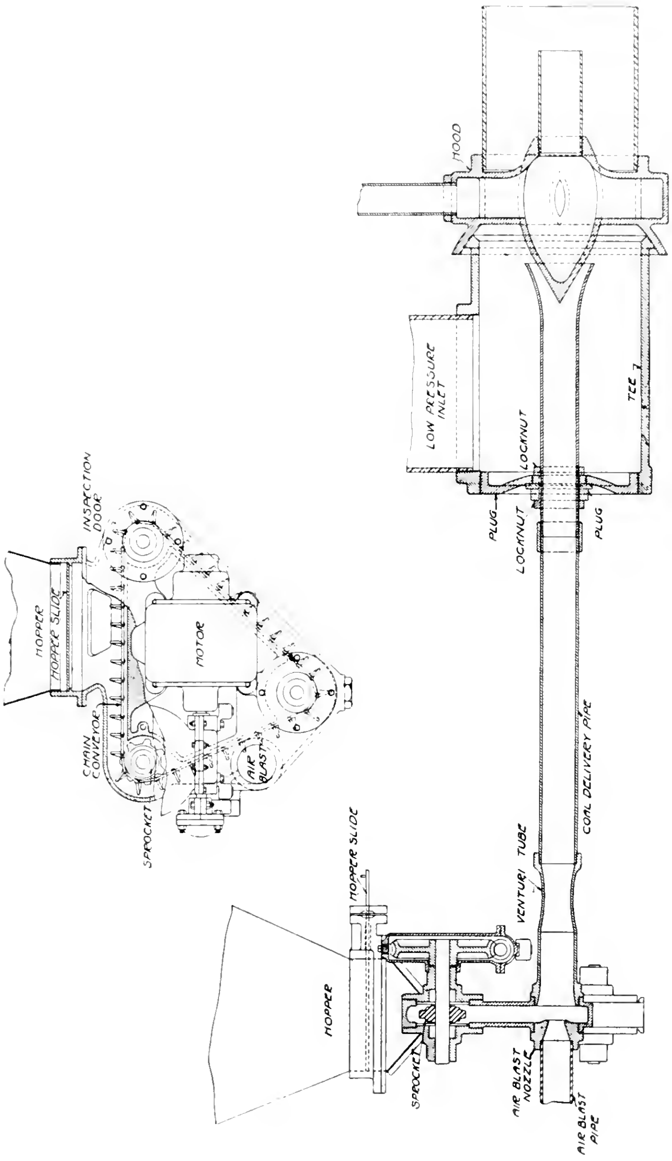
Fig. 4 shows a sectional elevation of a mechanically operated low-pressure powdered-coal feeding apparatus, also a sectional view of the feeder taken across the air-blast ports, showing the method of its connection with the burner.

By reference to the sectional elevation it will be noted that in this device an endless flight conveyor chain is used for feeding a stream of powdered coal in a continuous shower across the air-blast ports, and the excess fuel escaping the feeding action of the cross-current is automatically returned to the hopper by the endless flight conveyor chain.

Variable fuel feed is obtained through a direct connected variable speed motor, and the amount of fuel taken up by the cross-current of air will vary with the pressure of the air blast.

The air-blast inlet nozzle connecting with one side of the feeder case is reduced, the outlet side being flared, beyond which is a Venturi tube used to induce higher velocity of the mixture leaving the feeder, thereby causing a slight vacuum or pull throughout the case, the mixture continuing through the coal-delivery pipe to the burner. The cone extension on the hood of the burner enters the flared end of the coal-delivery pipe,

Fig. 4.


HOPPER
HOPPER SLIDE
INSPECTION DOOR
MOTOR
CHAIN CONVEYOR
SPROCKET
AIR BLAST
HOOD
LOW PRESSURE INLET
TEE
LOCKNUT
PLUG
LOCKNUT
PLUG
COAL DELIVERY PIPE
VENTURI TUBE
HOPPER SLIDE
HOPPER
SPROCKET
AIR BLAST NOZZLE
AIR BLAST PIPE

breaking the solid shaft of coal and air and deflecting it around the inner periphery of the burner pipe. The mixture takes the form of a hollow ring, in the centre of which an auxiliary blast is discharged, giving a very thorough atomization of the particles as they enter the furnace.

Figs. 3 and 4 serve to illustrate two forms of low-pressure mechanical feeders and burners in commercial use, modifications of which are also in successful operation, all involving the same general principle; namely, a mechanism which will give a uniform and properly proportioned mixture of coal and air, both under variable control, feeding the resultant mixture in a thoroughly atomized state into the furnace.

Feeders and burners of this type are used almost exclusively on the many forms of heating furnaces in the metallurgical arts. This method of burning powdered coal with low velocity of both air and coal produces a short flame, as the fuel combusts almost the instant it leaves the burner, and the heat thus produced is conveyed by the gases from the initial point of firing with less cutting action upon the material being heated and on the brick work.

Powdered coal will flush, and when once started will run like water. Screw feeding devices should, therefore, be made very long and of a reasonably fine pitch in order to set up enough friction and baffling action to prevent the coal from flushing through the feeding mechanism and causing irregular feed.

In the case of the feeding mechanism shown in Fig. 3, long screws would make a cumbersome and expensive device, and efficiency has been sacrificed in this form of feeder for the sake of compactness and cost, as feeders of this design in use at present will invariably flood. They have another very objectionable feature; namely, if the air blast is not turned on and the feeder started up, the screws will jam so hard that the motor is stalled. The arrangement of the inlet and outlet blast through the feeder case sets up a pressure in the feeder, the result being that it not only tends to arch the coal in the bin, but it blows the coal out of the bin or the feeder case, wherever a leak may occur. In addition, under normal running it consumes considerable power to operate.

In Fig. 4 the vertical flights and the conveyor chain have a baffling action which prevents flooding. Under operating con-

ditions it has been proved that the coal will not pack in the feeder should the air blast be cut off. The air-blast nozzle and Venturi tube, producing a suction through the case, have a tendency to prevent arching in the hopper, thus giving a more reliable and

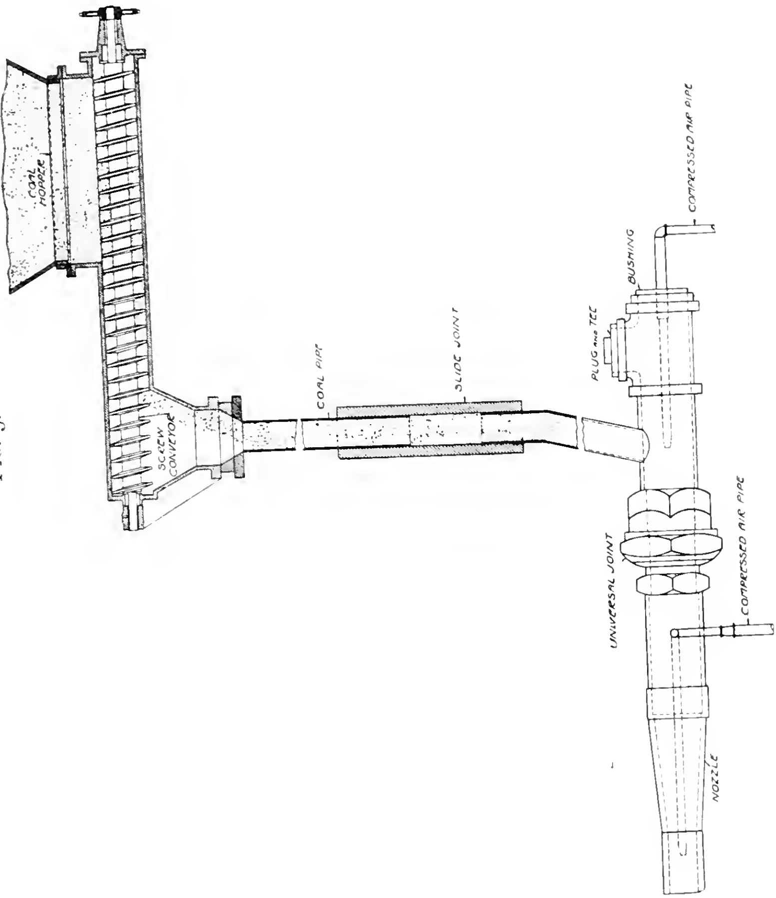


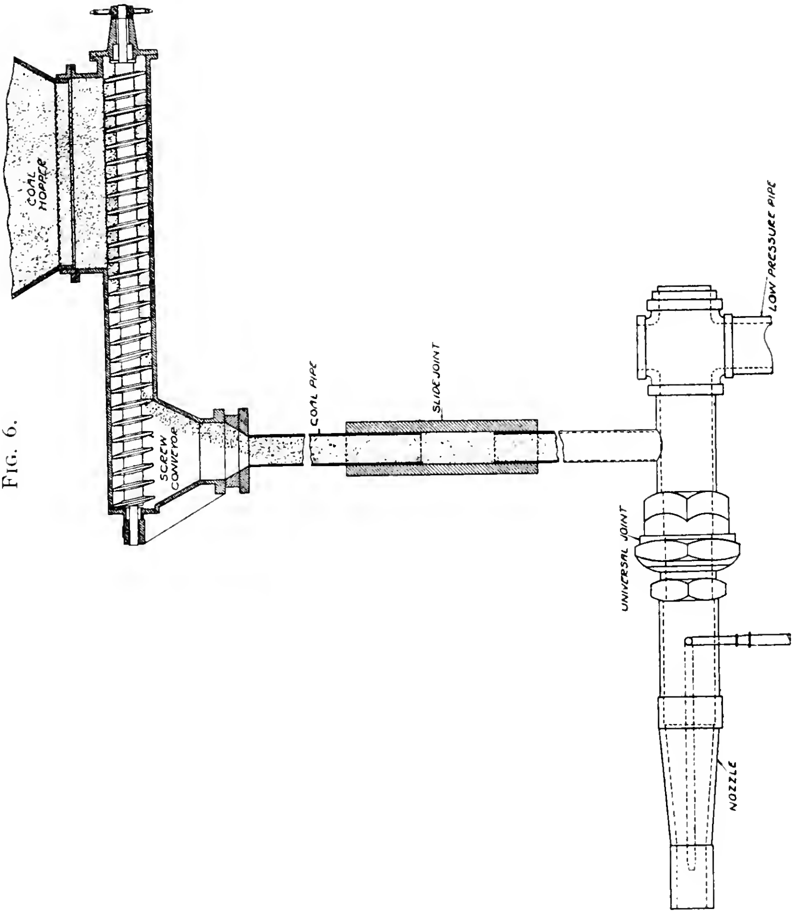
FIG. 5.

uniform feed. In addition, this suction prevents leakages, as there is always an inward pull on the case. This type of feeder takes one-tenth of the power to operate it as compared with the same capacity of screw feeding device shown in Fig. 3.

Fig. 5 shows a sectional elevation of a mechanically operated

high-pressure powdered-coal feeding apparatus. By reference to the drawing it will be noted that in this device a long screw of fine pitch conveys the coal from the hopper and discharges a uniform stream of powdered fuel into the coal pipe. This stream falls by gravity down the coal pipe and is picked up by a

FIG. 6.



cross-jet of compressed air as it enters the burner. The expansion of the compressed air in the larger diameter of the burner thoroughly mixes the coal and air, and this mixture is injected from the burner into the furnace at high velocity by the compressed-air jet at the end of the nozzle.

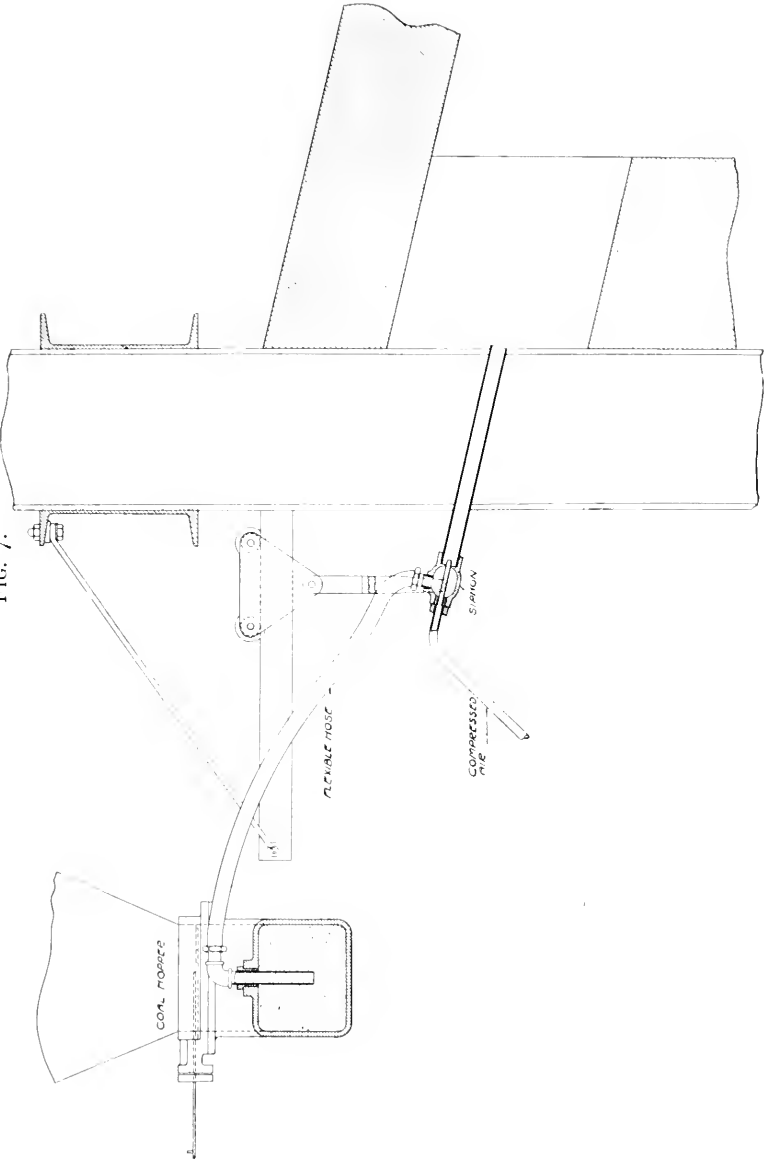


Fig. 7.

By varying the speed of rotation of the conveyor screw variable fuel feed is obtained.

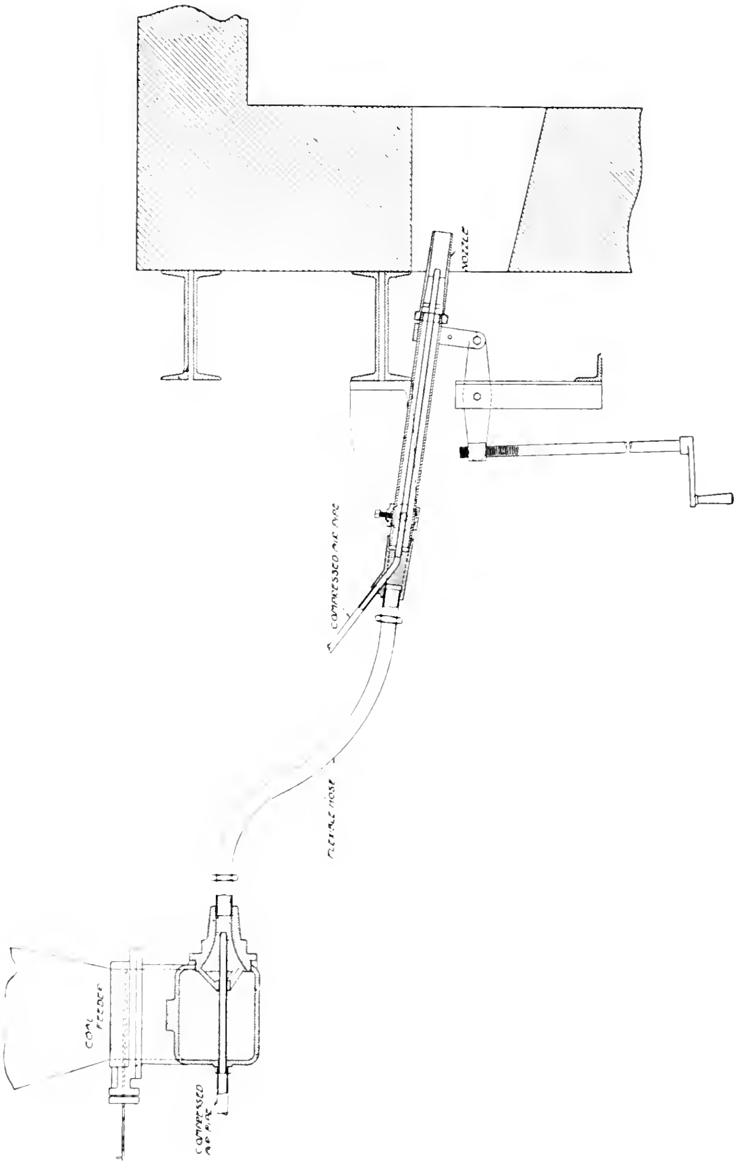


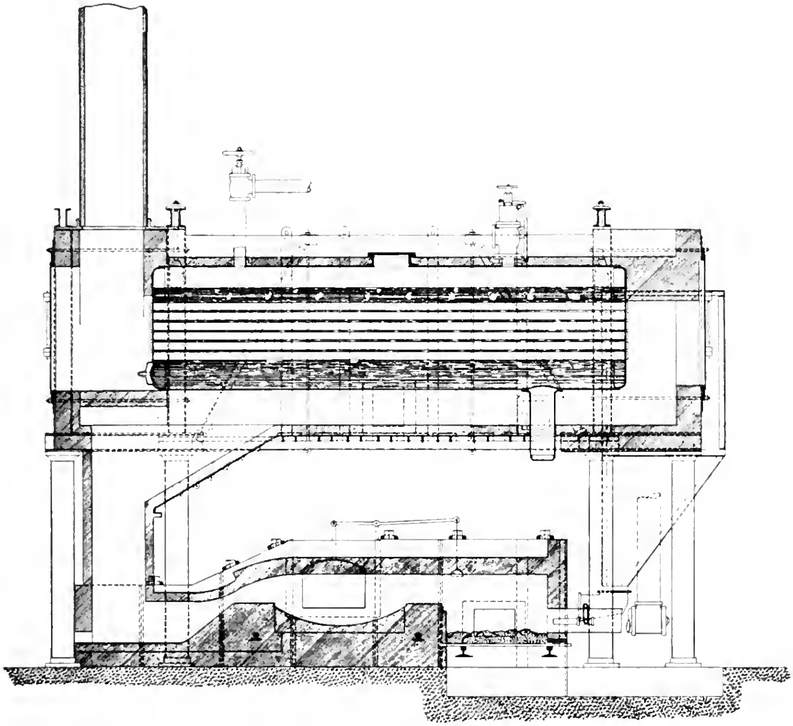
Fig. 8.

Fig. 6 illustrates a sectional elevation of a mechanically operated high-pressure feeding apparatus for powdered coal, which is similar in every respect to that shown on Fig. 5, excepting that

low-pressure air of one pound pressure is used to pick up the stream of coal delivered to the burner by the feeding device.

Fig. 7 illustrates a siphon type feeder and burner. By reference to the drawing it will be noted that the coal is siphoned from the hopper into the burner and discharged at high pressure into the furnace.

FIG. 9.



PUDDLE FURNACE

Fig. 8 illustrates another form of siphon type feeder and burner. By reference to the drawing it will be noted that a siphon is placed in the coal hopper, discharging a mixture of coal and air into the burner, and the siphon in the nozzle of the burner discharges the mixture at high velocity into the furnace.

Feeders and burners of the high-pressure type produce a long flame through progressive combustion and can be used only where the form of the furnace and the character of the work demand

that an elongated cutting flame be developed in close proximity to the work done. This method of application is adapted to open-hearth furnace practice, and ore nodulizing.

In the type of feeders and burners described it is interesting

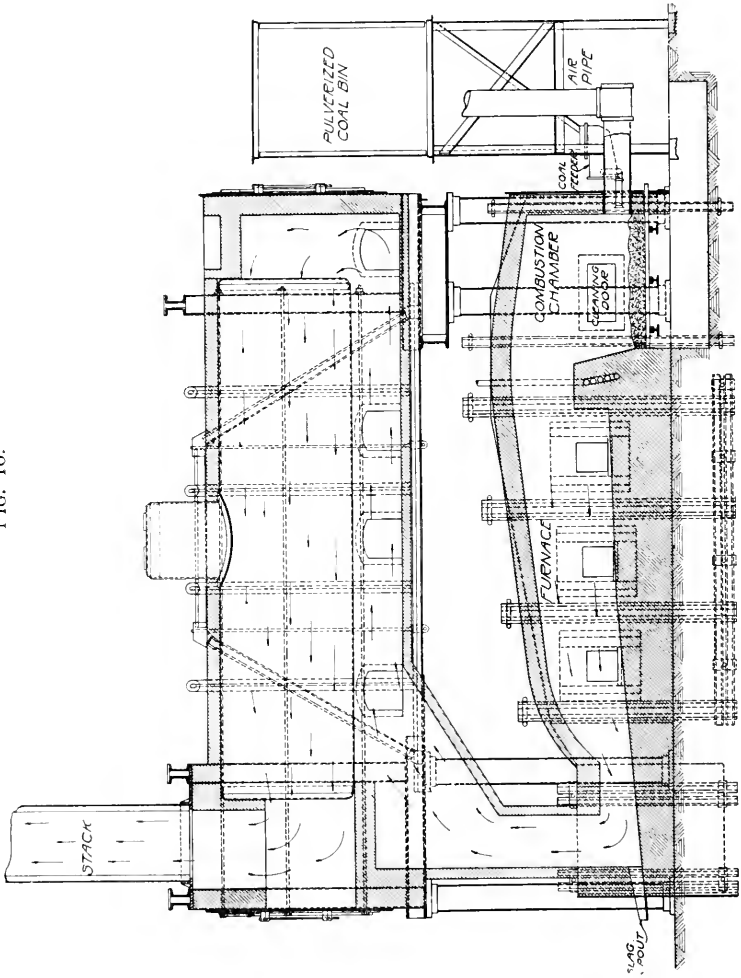


FIG. 10.

to note that the results obtained in the combustion of the fuel are equally good, whether the powdered coal is injected into the furnace from the burner at a velocity of 1500 feet per minute or of 25,000 feet per minute.

FURNACES.

In the metallurgical processes powdered coal has been applied with commercial success to various types of furnaces, such as annealing, puddling, heating, open-hearth, ore nodulizing, etc.

In order to insure success in applying powdered coal to furnaces, no matter what their type may be, one general rule must be obeyed; namely, that it be fed to the furnace at a uniform rate in a thoroughly atomized state, and that the furnace be so designed that complete combustion may take place while the coal is in suspension.

Fig. 9 shows a sectional elevation through a puddling furnace arranged with a return tube waste-heat boiler and equipped for burning powdered coal.

Fig. 10 shows a sectional elevation of a three-door heating furnace of the type generally used in heating iron piles and steel billets, also arranged with a waste-heat boiler and equipped for burning powdered coal.

In both of these installations a low-pressure burner discharges the mixture of coal and air into a combustion chamber. As the fuel combusts the heat thus produced is conveyed over the bath or furnace hearth, as the case may be, and the waste gases pass through the boiler setting to the stack.

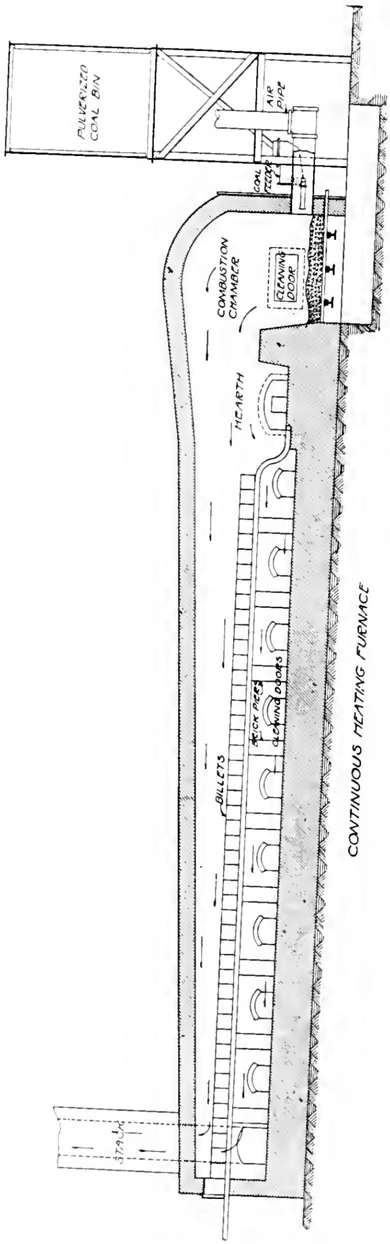
Loose grate bars supporting a bed of about 9 inches of ash form the combustion chamber hearth, and a large portion of the ash contained in the coal collects over this surface. After each heat the accumulation of ash is raked out through the cleaning doors, and once a week the grate bars are dropped and the chamber thoroughly cleaned.

The accumulation of slag at the base of the uptake flue is tapped out from the slag runner. The ash which falls upon the material in the furnace is too small a proportion to cause any ill effect. In the boiler settings and flues considerable ash is deposited in the form of an impalpable powder, which is cleaned out once every twelve hours.

As to the economy of fuel on puddling furnaces, the use of powdered coal has shown an average saving of about 30 per cent. to 36 per cent., and on heating furnaces 15 per cent. to 25 per cent. For every pound of coal fired the waste-heat boilers show an evaporation of from seven to eight pounds of water.

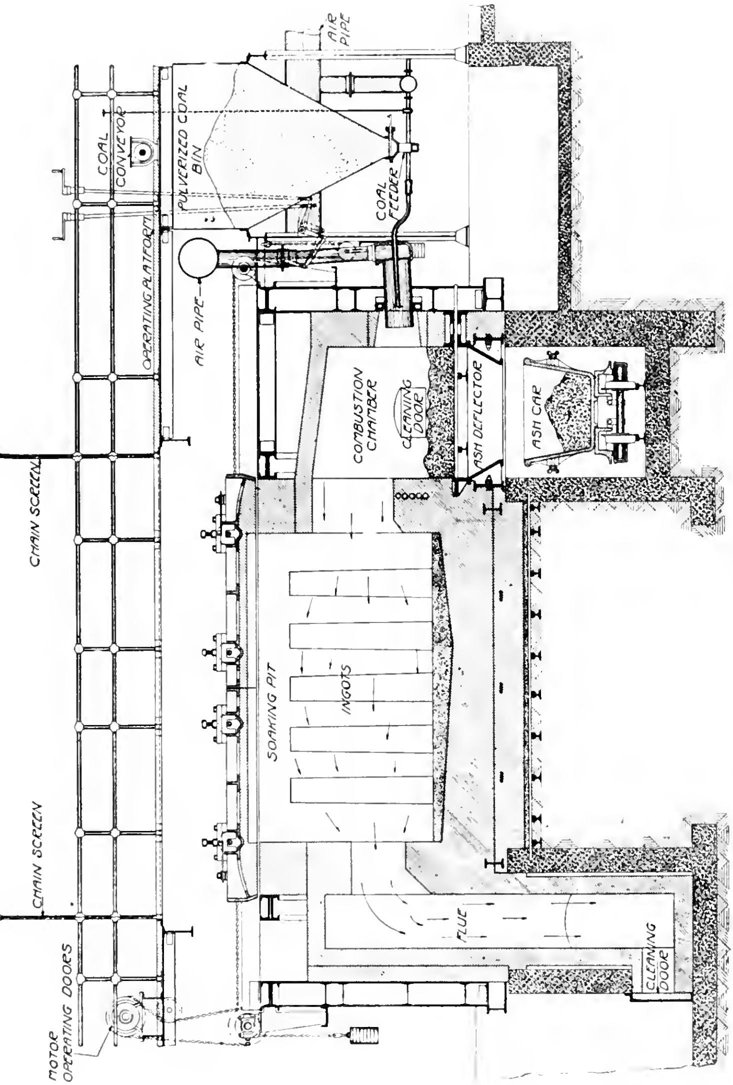
Fig. 11 shows a sectional elevation of a continuous heating

FIG. 11.


PULVERIZED COAL BIN
AIR PIPE
COAL FEEDER
COMBUSTION CHAMBER
CLEANING DOOR
HEARTH
BILLETS
BRICK PIERS
CLEANING DOORS
CONTINUOUS HEATING FURNACE
STACK

furnace for heating steel billets, and equipped for burning powdered coal.

FIG. 12.



The use of powdered coal as a fuel in soaking pits represents probably the latest application of this form of fuel in the metallurgical arts. Fig. 12 shows a sectional elevation through a soak-

ing pit equipped for burning this form of fuel. The drawing clearly shows the construction, and the mode of operation will

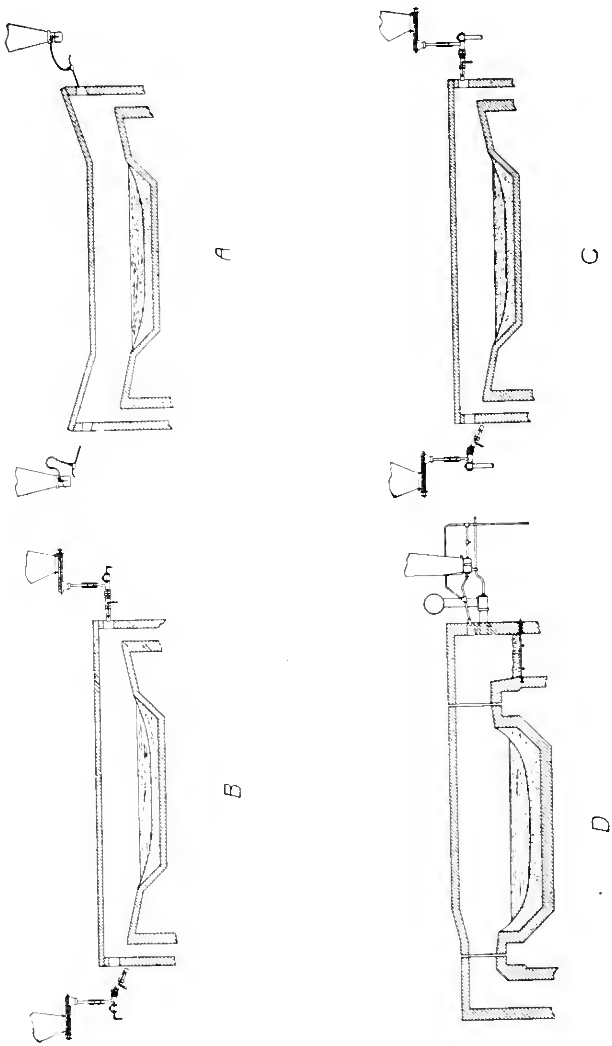


FIG. 13.

be readily understood. Five double soaking pits of the general design shown are now in operation and are giving very satisfactory results.

Another recent application of powdered coal is in open-hearth

furnace practice. At this time four different steel plants are using this form of fuel in open-hearth furnaces with encouraging results. While all the installations are more or less in an experimental stage and not as yet fully developed, owing to the limited time of application, the results obtained thus far have fully demonstrated the economy of powdered coal over oil and show equal economies with producer gas.

Fig. 13 shows the four different methods at present employed for applying powdered coal to open-hearth furnaces.

A, B, and C represent installations in which high-pressure siphon type burners are used, similar to those shown in Figs. 5, 6, and 7. One burner is placed on each end of the furnace, the fuel being reversed as in the case of producer gas. As the gas flues are eliminated in this process, the regenerative chambers in most cases have been enlarged, and in place of checkers staggered arches or parallel walls have been built to give the necessary regenerative area. There are at the present time one 75-ton, three 60-ton, and four 35-ton open-hearth furnaces of the regenerative type in operation, with modifications in the construction of the regenerative chambers as described.

At one plant the results obtained have been so encouraging that a second furnace of 75 tons capacity is now under construction.

D represents a somewhat radical departure from the old-time theories of open-hearth furnace practice. By reference to the diagram it will be noted that the burners are arranged only at one end of the furnace, the path of the flame being always in one direction. There are no regenerative chambers, air at room temperature being used for combustion of the fuel.

The theory underlying this method of applying powdered coal to open-hearth furnaces is:

First, the fuel is burned above the bath, and all the heat contained in the coal is instantly developed in the furnace.

Second, as the path of the flame is in one direction, all parts of the furnace are maintained at the same temperature.

Third, by reason of their high radiating capacity, the infinite number of minute incandescent particles in the powdered coal communicate the heat by radiation,

and not by convection, thus eliminating the necessity of bringing the surrounding air to the temperature of the coal particles.

Fourth, all the heat in the waste gases is conserved and used in the production of steam.

The extra fuel consumed, due to the use of cold air, is offset:

First, by the elimination of all loss in the gas producer process.

Second, by the elimination of all loss due to frequent reversals.

Third, by the elimination of all loss in waste heat taken up by the regenerative chambers.

Fourth, by the elimination of the expensive maintenance cost of producer plant and regenerative chambers.

Fifth, by the greatly reduced first cost of installation.

Fig. 14 shows a sectional elevation of this furnace. A section through the combustion chamber looking towards the back wall is shown in the upper left-hand corner. By reference to this view it will be noted that three burners are employed—the central one of the high-pressure siphon type shown in Fig. 8, the two side ones of the low-pressure type shown in Fig. 4.

As powdered coal requires a high temperature for ignition and maintained combustion, there would be no incentive for the powdered fuel to ignite in the cold furnace after charging, especially since the air necessary to support combustion is also cold.

The combustion chamber in this installation is maintained at a high uniform temperature at all times by the two low-pressure burners. The high temperature maintained in the combustion chamber preheats the air furnished to support combustion, and, as the high-pressure siphon burner discharges the powdered coal through the hot zone of the chamber, complete combustion of the fuel is insured.

Auxiliary air for combustion is admitted through the back wall of the combustion chamber at the roof line.

The accumulation of ash in the combustion chamber is raked out through the cleaning doors after every heat and is discharged through a trap door in the charging floor into the ash car below.

From a metallurgical standpoint, the deposit of ash on the bath is too small an amount to be noticeable.

In the slag pocket at the bottom of the vertical flue the ash and the brick slag form a thick, pasty mass, the tough consistency

of which makes its removal difficult. Beyond this point the ash settles in the flues as an impalpable powder. After each heat it is stirred up by inserting a compressed-air jet through the separate

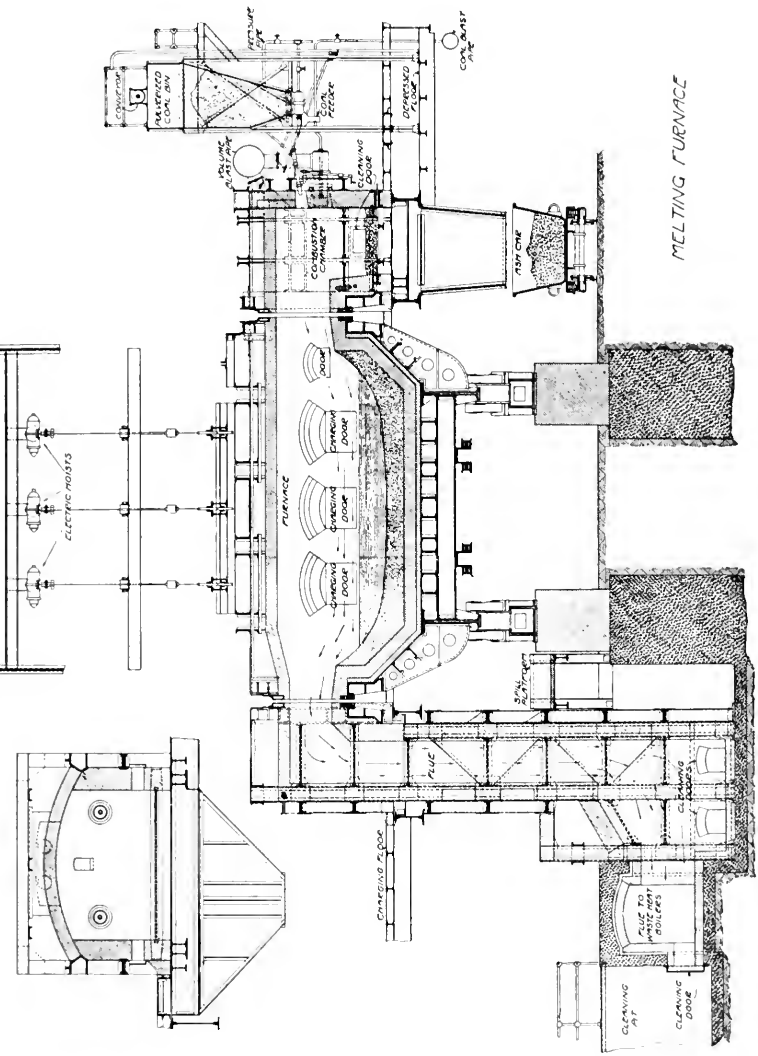


FIG. 14.

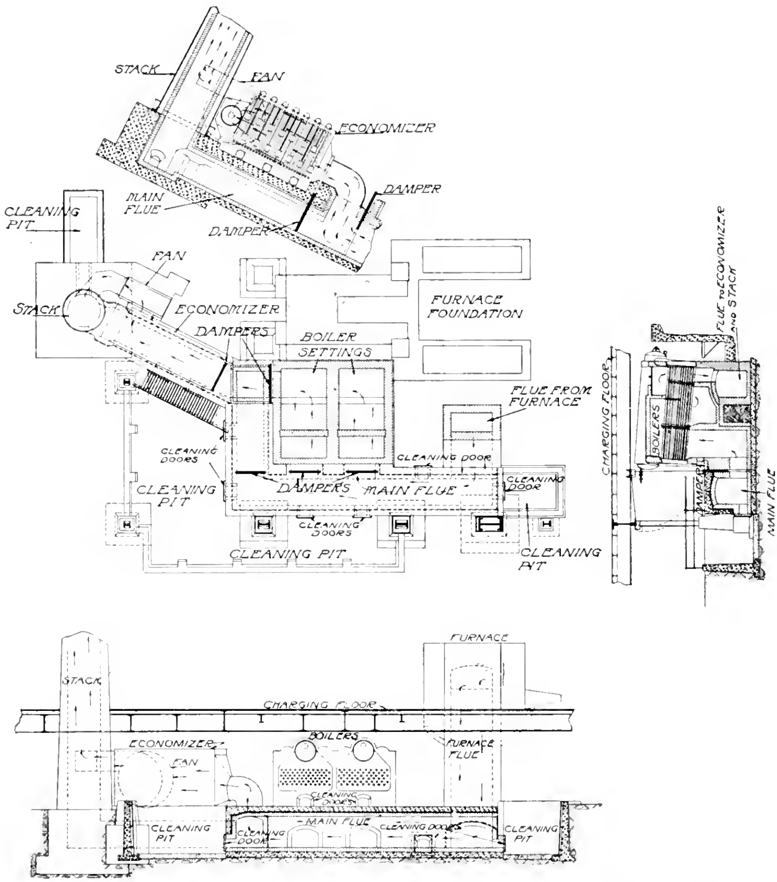
cleaning doors of the flues. The ash clouds thus produced are picked up by the flue draught and are carried in suspension out of the stack.

The boiler tubes are cleaned with steam blowers four times each day.

The course of the waste gas is indicated by the arrow marks, and is shown discharging into the flue connecting with the waste-heat boilers.

Fig. 15 shows a plan and elevation of the waste-heat plant, also a sectional elevation through the boilers and economizers.

FIG. 15.



The course of the waste gases can be followed by the arrow marks, and the general operation will readily be understood by reference to the drawing.

It will be noted that by the arrangement of the flues and

dampers the whole waste-heat plant may be by-passed. The economizer and both boilers may be by-passed either separately or in combination, as desired. The flexibility of this arrangement permits any adjustment or repairs to the boilers or economizers without affecting the operation of the furnace.

Within the past few months four 50-ton basic open-hearth furnaces thus arranged have been placed in operation. In this short period operating conditions have demonstrated the soundness of both the underlying theory and the engineering principles involved in this method.

Compared with producer gas, equally high temperature is attained.

Uniform temperatures throughout the furnace are maintained.

Heats can be made within reasonable time.

Fuel consumption is high. This, however, is offset by the fact that the waste-heat plant produces an average evaporation of six and one-quarter pounds of water per pound of coal fired in the furnace.

Compared with the best boiler-room practice, 62½ per cent. of the fuel consumed by the furnace is used in the generation of steam, leaving 37½ per cent. chargeable to steel production. Based on this reasoning, economies over oil and producer gas are fully substantiated.

In the use of powdered coal in metallurgical furnaces we have arrived at a stage of development where fixed rules may be laid down for its application which, if strictly followed, will result in high economy and efficiency.

The personal equation is the important factor in operating part of the apparatus as developed thus far. It is necessary to depend too greatly upon this uncertain element.

In the drying process the operator may at any moment upset the complete equilibrium of a plant either by overheating the coal or by not drying it enough.

In the furnace operation three or four separate adjustments are required, depending on the burner used, each adjustment bearing a fixed relation to the others. These adjustments are: The control of the coal feed, the control of the coal blast, the control of the volume blast, and the control of the furnace draught, where mechanically operated low-pressure feeders and burners are employed, all of which controls are separately left

to the judgment of the operator. When we consider that there is no fuel so sensitive to correct application as powdered coal, and when we realize the exact precision required in its manipulation, the dependence placed on the personal element is at once apparent.

In order to obtain uniform conditions, it is necessary to eliminate the personal equation as far as possible. In the drying process this might be accomplished by an automatic control of the coal feed governed by the temperature of the dryer cylinder. In the case of the burners and feeders this might be done by a single adjustment regulating and supplying the correct proportion of air and coal, with provision for adjusting the air and coal independently in order to obtain correct proportions for different grades of fuel, thus producing an absolutely uniform combustible mixture, which will be maintained, regardless of the quantity supplied, after once setting the adjustment.

The high economy and efficiency of powdered coal in the metallurgical processes, under the limited application of this fuel and the limited development of apparatus, provide an index of its possibilities under more general use. With a further development of apparatus this form of fuel doubtless will eventually supplant oil, tar, and producer gas in the varied fields where they now hold supremacy.

THE DETERMINATION OF THE CONSTANT OF A SOLENOID.*

BY

S. R. WILLIAMS, PH.D.,

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WHETHER measuring the earth's magnetic field by means of an earth inductor or the field in the slit of a radially divided toroid by means of a few turns of wire, the exploring coil has become a useful adjunct in measurements of magnetic field intensities. Particularly is this true since the advent of sensitive moving coil galvanometers. In order to know a magnetic field completely, both its intensity and distribution must be determined. Of the varied and many means at our disposal for thus mapping out a magnetic field, perhaps none lends itself so readily to both field intensity measurements and topographical surveys as does the exploring coil. This adaptability is well illustrated in the following special application:

TESTING THE CONSTANT OF A SOLENOID.

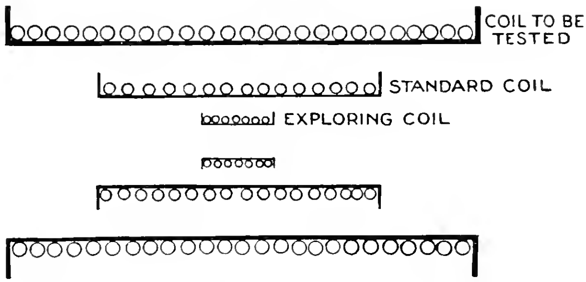
The constant of a solenoid which has been carefully wound may be found with considerable accuracy from its dimensions, so that experimental tests on the constant may be checked up very closely. Even with the greatest care in winding we are always glad to avail ourselves of any means that will assure us whether any short circuits have occurred during the winding. In other words, we want the satisfaction which comes from contemplating, side by side, the calculated and observed values and finding that they agree.

After winding several solenoids and attempting to verify their constants experimentally by various means, I have found the following method a very practical one. It is based on an old method, common to many laboratories, in which a magnetometer needle is placed at the centre of two coaxial coils, one of which is a standard coil and the other the one to be tested, and

* Communicated by the author. Read by title before the Ohio Academy of Science, Columbus, Ohio, November 28, 1914.

the deflections compared when the fields of the two coils reinforce and when they oppose each other. In the measurement of magnetic fields we may make use of the principle that a magnetometer may be replaced by an exploring coil in circuit with a ballistic galvanometer. We thereby gain all the advantages which a moving coil galvanometer offers over a moving magnet type, chief of which is the freedom from magnetic disturbances. In the above magnetometric method referred to, therefore, we may replace the magnetometer by an exploring coil in circuit with a ballistic galvanometer. In the case of testing a long solenoid, whose inner diameter is very small, the magnetometer is practically out of the question. One solenoid which the author wound was 100 cm. long and had an inner free diameter of 2.54 cm. Not only did the small inner diameter necessitate a very short sus-

FIG. 1.



pending fibre for the needle of the magnetometer, but the deflections of the needle could not have been read with any accuracy, since the magnet must necessarily be placed at the centre of the long, narrow opening of the coil.

With the exploring coil replacing the magnetometer (Fig. 1), let the two coaxial coils, centred at the same point, be connected in series and the current, I, flowing through them so directed that the fields reinforce each other. If S is the constant of the solenoid and G that of the standard coil, then when the current is suddenly broken in the circuit the induced electromotive force in the exploring coil will set up a current through the ballistic galvanometer such that its deflection, d_2, will be given by the relation:

$$IS + IG = kd_2 \qquad (1)$$

where k is a constant dependent upon the ballistic galvanometer.

By reversing the current in one coil and not in the other and again suddenly breaking the circuit, a deflection, d_1, is obtained such that

$$IS - IG = kd_1 \quad \ldots\ldots (2)$$

where the field of the coil, G, has been reversed. Dividing equation (1) by equation (2) and solving for S, we obtain

$$S = G\frac{d_2 + d_1}{d_2 - d_1} \quad \ldots\ldots (3)$$

which is the constant of the solenoid in terms of the constant of the standard coil, and the deflections of the ballistic galvanometer for the two conditions. It will be noted that so long as the current remains constant the current I does not enter into the computation, neither does the constant of the ballistic galvanometer. For measuring the current through the coils all that is needed is an ammeter which will indicate that the current is constant when the fields reinforce and when they oppose each other. When the current is supplied from a storage battery it is easily kept constant enough.

Equation (3) should apply whether the field through the exploring coil is changed by suddenly breaking the electric current or by suddenly rotating the exploring coil through 180 degrees. For a solenoid with a large inside diameter, the author feels that the rotating exploring coil may be used to advantage, as by its use the solenoid circuit does not need to be disturbed for a series of readings and the integral electromotive force is also double that obtained when the field is simply made zero in the coil. Both the rotating and fixed types of exploring coil were used in testing a coil employed in previous work [1] and no difference in results greater than experimental errors could be detected.

The question may be raised, Why determine the constant of a solenoid [2] in terms of another coil whose constant is ordinarily obtained from its dimensions, although not necessarily so? In the experiment on which this work is based, a tangent galvanometer coil was used for the standard coil, and we may answer

[1] *Phys. Rev.*, vol. 34, p. 40, Jan., 1912.

[2] By a solenoid is meant a coil whose constant is computed by the formula,

$$H = 4\pi nI\frac{l}{\sqrt{l^2 + r^2}}$$

the above question by saying that the constant of the tangent galvanometer coil is easily computed and not so much risk arises in the winding that there will be short circuits. Furthermore, if the constant of the solenoid determined in terms of the constant of the tangent galvanometer coil does check with that obtained by computations from the dimensions of the solenoid, we feel a greater confidence that the value of the constant we have found is the correct one. There are, however, objections to the tangent galvanometer coil as a standard. These are: (1) the field at the centre is not uniform enough over a sufficiently large space at its centre and (2) errors in measuring the dimensions creep in too easily. The first objection may be overcome by using a Helmholtz coil, but objection (2) holds even more strongly for the last type of coil. Watson,[3] in measuring the horizontal component of the earth's magnetic field, used a Helmholtz coil, and, in order to obtain an accuracy of one part in 10,000, used a coil 60 cm. in diameter and measured the radius down to 0.003 of a centimetre. This size of a coil is inconvenient to use as a standard in this work, and a smaller coil decreases the accuracy of the work.

If we examine the formulæ for the constants of various types of coils we find that the one used in computing the constant of a solenoid has fewer quantities which are affected by the dimensions of the coil. The formula is practically dependent only on the number of turns, n, per unit length, which, as will be shown later, may be made very accurate. Accordingly it was thought advisable to adopt the solenoid type of coil as a standard, making the diameter of the same as small as practical and placing it inside of the solenoid or coil to be tested. From equation (3) it is evident that so far as theory goes the standard coil may be made coaxial either outside or inside the other coil.

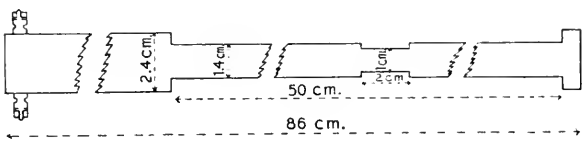
In the work as actually carried out the standard coil was made up in the following form: a rod of non-magnetic "Bakelite,"[4] 86 cm. in length and 2.4 cm. in diameter, was turned down in a lathe so as to form a spool at one end, whose length was 50 cm. and diameter 1.4 cm. (see Fig. 2). At the middle of this long spool another channel was cut out 2 cm. long and

[3] *Phil. Trans. Roy. Soc.*, p. 432, vol. 198, 1902.

[4] Specimens of hard rubber showed magnetic properties.

2 mm. deep. In this smaller channel 600 turns of No. 37 silk-covered copper wire was wound and the ends carried along in a groove to two binding posts at the end of the "Bakelite" rod. This secondary or exploring coil was covered with hard wax and smoothed to the same diameter as the spindle, which was 50 cm. long, on which the primary was to be wound. The rod was cleaned as thoroughly as possible to free the surface from any particles of steel which might have stuck in turning down the rod in the lathe. For the primary, No. 18 double cotton-covered copper wire was used and wound in four layers, which just filled the channel turned out for the primary. As each layer was put on it was thoroughly shellacked. The winding was done on a lathe and all parts of the wire and coil were kept from contact with the iron parts of the lathe. The screw-cutting attachment was adjusted so that the wire, as it was fed onto

FIG. 2.



the coil, was carried along at the same rate as the windings of the coil. While the number of turns for each layer was not the same, yet this arrangement for feeding the wire to the coil gave the number of turns per centimetre in each layer with good uniformity. There is no question but what the method employed by Jenkins [5] and others in winding solenoids gives greater uniformity in the number per unit length than the method employed in this work. Jenkins accomplished this end by cutting an accurate thread along an insulating tube and winding bare wire under tension in this groove. Inasmuch as I wanted a standard coil of several layers, this seemed impractical unless the coil could have been built out of a series of telescoping "Bakelite" tubes. The small inner diameter of the solenoid to be tested prevented the use of more than two tubes.

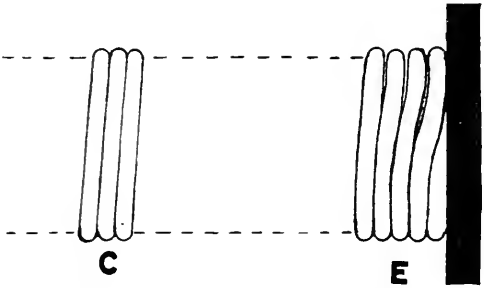
The constant of the standard coil was computed by means of the well-known formula [6] already given for solenoids. The

[5] Jenkins, *Phil. Mag.*, Ser. 6, vol. 26, p. 752, 1913.

[6] Watson, "A Textbook of Practical Physics," p. 522, 1906.

total field strength was taken as the sum of the fields due to the various layers. For a long time there was a persistent difference between the computed and observed values of the solenoid tested. In the case of the solenoid, one metre in length, this difference amounted to about one-half of one per cent. and was always in a direction such that the computed value was less than the experimental. After investigating, seemingly, every possible chance of error, I finally found, what apparently has been overlooked in many important researches, that in the various coils which were tested, n, the number of turns per unit length, was invariably greater at the centre than at the ends. This is, I believe, due to the fact that as the wire comes from one layer up to the next one at each end of the coil in the wind-

FIG. 3.



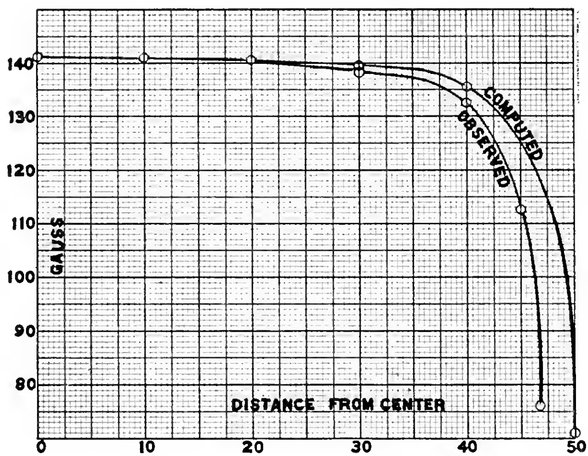
ing, the turns which lie next to the wire where it comes up must curve out around it, and in so doing cannot be made to lie so close together as at the middle of the coil where the turns have straightened out (see Fig. 3). Ordinarily we divide the total number of turns in a layer by the length of the layer in order to find n. This leads to a systematic error, as indicated above, if, as I have found, the value of n is smaller at the ends than in the middle of the coil.[7] The turns at the ends do not have so much effect on the field at the centre as those turns wound about the centre, and therefore they should not be given equal weight with those at the centre when it comes to finding the value of n. The correction for this discrepancy was made by finding n for various parts of the coil and then the average when these various values of n had been weighted proportional to their

[7] This effect is very noticeable in the windings of the field coils on older types of dynamos; in fact, it must be present in every solenoid as ordinarily wound.

effects upon the field at the centre of the coil. When this was done the computed and observed values of the field at the centre of the coil agreed within the limits of accuracy of the method, which was 1 : 1000. The fact that the value of n was less at the ends of the coil than at the centre may be shown in another way. If the observed values of the field intensity along the axis of the coil are compared with the computed it will be found that the observed values drop off more rapidly than the computed as one passes from the centre out toward the ends. This is shown in Fig. 4.

The large solenoid to be tested, of which mention has already

FIG. 4.



been made, was wound in 24 layers and had a total of 11,251 turns. It was wound on a brass tube, 2.54 cm. inner diameter and 3.8 cm. outer diameter. This tube, with its end pieces, was slotted lengthwise to prevent induction currents when alternating currents were sent through the coil. The computed constant was obtained in the manner just indicated and found to be 142.362 gauss, while the value as determined experimentally was 142.445. The last value was the average of twenty observations. This difference means a discrepancy of less than one part in a thousand between the observed and computed values, which for this particular coil means that not more than 10 to 15

turns could be cut out by a short circuit without being able to detect it. However, by refinements which have been indicated, such as methods of winding and construction, greater accuracy can be secured, and there seems to be no reason why the accuracy could not be pushed to one part in 10,000 (1 : 10,000). It would seem that in the end the accuracy of the method rested upon what refinement could be made in detecting changes in the current which flowed in the two coils. The best instrument which I had could be read only to one part in one thousand (1 : 1000). It is to be noted that in this method it is not a matter of reading the absolute values, but merely detecting variations.

The ballistic galvanometer was a Leeds & Northrup instrument, type HB, having a resistance of 18 ohms, a period of deflection equal to 9 seconds, and whose sensibility is 122 megs. It seemed to be a very satisfactory instrument for this kind of work.

The standard coil was next used on a solenoid [8] which had seen service in previous work and also on an ordinary tangent galvanometer coil and a Helmholtz coil, all of whose constants could be computed with a fair degree of accuracy. Thus not only were the constants of the various coils ascertained with greater certainty, but, conversely, the constant of the standard coil could be said to have been more firmly established.

SUMMARY.

1. This paper has given a practical method for testing the constant of a solenoid by experimental means.

2. The method recommends itself because of its simplicity. The constant of the solenoid is determined in terms of the deflections of a ballistic galvanometer and the constant of another coil taken as a standard. If a long, slim solenoid is used for the standard, the only quantity which must be known with great accuracy in determining its constant is the number of turns per unit length. The constant of the ballistic galvanometer does not need to be known, neither does the ammeter, which indicates the constancy of the current in the coils, need to be calibrated. Even the exploring coil does not need to have its inductive area determined. Once the constant of the standard coil has been definitely fixed, the method could not be much simpler.

[8] *Phys. Rev., loc. cit.*

3. It is evident that the exploring coil could have been placed first in one coil and then in the other and the deflection observed when only one field was suddenly reduced to zero. In such a case,

$$S = G \frac{d_2}{d_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This last equation appears simpler. The author believes, however, that by keeping the two coils in series it will be easier to keep the current constant, because there is absolutely no change to be made in the circuits except to throw a reversing switch for one coil. Using the coils separately would necessitate change of circuits; also keeping the coils in series insures that in breaking the circuit the field due to both coils must vary simultaneously. Of course, difference in rate of decay of the magnetic fields should not affect the results if the period of deflection of the galvanometer is large enough.

4. An investigation as to what ratio of S/G would give the least error in S shows that when $S/G = 1$ the error in S should be a minimum. This is an impossible condition, as the d_1 in equation (2) becomes equal to zero. If the experiment is worked as a zero method it would be necessary to have each coil on a separate circuit and so arranged that the two fields could be made to just neutralize each other. When this occurred there would be no deflection of the galvanometer and equation (2) would then be written:

$$I_1S - I_2G = 0$$

$$S = G \frac{I_2}{I_1}$$

This was tested out, but was not so sensitive as the method finally pursued. In this zero method it would be necessary to know the absolute value of the current, which would mean the calibration of one or two ammeters.

5. This work has shown that great care must be used in winding a solenoid if the constant is to be obtained by computation. The author would recommend concentric "Bakelite" tubes where several layers are to be employed, and the winding carried out similar to the method used by Jenkins.[9] If the constant of the solenoid is to be determined by the method sug-

[9] Jenkins, *loc. cit.*

gested in this paper, then the winding need not be carried out with such extreme care.

6. Investigating the constant of a solenoid has brought out the fact with renewed earnestness that what we work with in a great many experiments is not a uniform field all along the axis of the solenoid, but, as shown by Fig. 4, it is a field that is continually decreasing as one goes from the centre of the coil out toward the ends. In work of measuring the magnetic properties of various substances this is too frequently lost sight of, and in studying such phenomena as the magnetostrictive effects everyone seems to have fallen into the error of considering the value of the field strength at the centre of the solenoid as holding constant very nearly to the ends. A consideration of the equation for the field strength at any point along the axis of a solenoid will soon convince one of this point, viz.,

$$H = 2\pi n\mathrm{I}\left[\frac{D+\frac{l}{2}}{\sqrt{(D+\frac{l}{2})^2+R^2}} - \frac{D-\frac{l}{2}}{\sqrt{(D-\frac{l}{2})^2+R^2}}\right]$$

where D is the distance from the centre of a solenoid of length l and radius R. It was from this equation that the computed values for Fig. 4 were obtained.

So far as the author knows no one has done in a practical way for solenoids what Maxwell did for galvanometer coils, viz., determine what the form of a coil should be in order to get certain desired fields. At present work is being done on this problem. It seems quite certain that the field may be kept up to a constant value along the axis much farther from the centre than is now done by ordinary solenoids

In closing, expressions of appreciation are due Mr. Ray Calhoon, an advanced student in the department, for the valuable assistance rendered in making long and tedious series of observations.

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VICTOR MEYER—HIS LIFE AND WORK.*

BY

B. HOROWITZ, Ph.D.

I. HIS LIFE.

MODERN chemistry, little more than a century old, shows four outstanding landmarks in its evolutionary course: (1) the Foundation Period, with its eye to quantity (as represented by Lavoisier and Berzelius); (2) the Classification Period, with its basis in system (Dalton and Mendeleeff); (3) the Physico-chemical Period, with mathematics as its corner-stone (Arrhenius, Van't Hoff, Ostwald); and (4) the Period of Radio-activity—the outcome of the discovery of radium (the Curies, Thompson, Rutherford). Early in its onward march the science came to be divided into two fields: the inorganic and organic. Between the first and second periods the latter was distinctly subordinate to the former. The pioneer work of Liebig and Wöhler, who showed connecting links between chemistry and the sciences of botany, agriculture, and physiology, quickly swung the pendulum in the direction of organic chemistry; so that we find that between the second and third periods the "organicists" were not merely in the ascendency, but had all but well-nigh supplanted the "inorganicists." Then came a totally new era with the entrance of mathematics upon the scene. Many entered the new school. Some, however, under the leadership of Fischer, turned their attention to the application of chemistry to physiology; others, following in the footsteps of Perkin and Baeyer, began to build up the chemistry of commerce.

Victor Meyer, the subject of this sketch, belongs to the school of pure organic chemists—to the period when organic chemistry was in its ascendency. He easily takes his place among the foremost pioneers in this phase of the science. He began work when the superstructure of organic chemistry had yet to be built up, and in this building process few can claim the share he can. When the beauty and symmetry of the building was all but apparent Meyer passed away. The man of forty-nine [he had reached

* Communicated by Dr. Joseph S. Hepburn.

that age when he took his own life], with the rare mind that was his, could still have accomplished much.

Meyer * was born in Berlin on September 8, 1848. His father, a prosperous Jewish merchant and a man of high intelligence, surrounded himself with the *élite* of the intellectual element of the city. The chemist Sonnenschein, then a *privat-docent* at the University; Bernstein, the founder and editor of the *Volkszeitung;* Franz Duncker, Love-Kalbe, Major Beitzke (author of the "Thirty Years' War"), Schulze-Delitzsch, and Berthold Auerbach were frequent visitors to the house. It was in such an atmosphere that Victor Meyer was brought up.

Together with his brother, Victor received his earliest instruction from his mother. Later a private tutor prepared the children for the gymnasium, and this Victor entered when he was ten years old.

During these early years at the gymnasium, Meyer's leanings were rather towards literature than science. The drama especially had a strong attraction for him. Indeed, at fifteen, the boy had quite made up his mind to become an actor. To his father's remonstrances, who watched these developments with much perturbation, Victor replied: "Never can I become anything else—never! I feel it. In any other profession I shall remain a good-for-nothing the rest of my life."

However, in the meantime the lad continued his academic studies, and in the spring of 1865 he passed his matriculation examination (*Abiturientenexamen*). Hoping against hope that possibly the University atmosphere would tend to direct Victor's thoughts in another direction, the family persuaded the youth to proceed to Heidelberg, there to attend some lectures in the company of his elder brother. What the incessant arguments of the parents and friends had failed to do, the chemical lectures of one of the professors easily accomplished. In Bunsen the young man encountered one of those rare minds who can see and demonstrate the beauty and poetry of anything they happen to be engaged in.

* For much of my material I am indebted to Richard Meyer's Life of his brother.[40] Carl Liebermann's Memorial lecture delivered to the Fellows of the German Chemical Society [41] is a beautiful homage to a departed friend. Professor E. Thorpe, in his Essays on Historical Chemistry,[42] has an interesting article on Victor Meyer.

From the lips of Bunsen chemistry issued forth as a song to Nature, and as a song to Nature Meyer caught the refrain.

Small, and quite childish in appearance, the seventeen-year-old boy enrolled as a student of the University. During the first semester he attended Hofmann's lectures in Berlin, so as to be near his parents. After that he took up his abode in Heidelberg. Here he followed Kirchhoff's lectures on physics, Kopp's on theoretical chemistry, Helmholtz's on physiology, Erlenmeyer's on organic chemistry, and Bunsen's on general chemistry—truly as illustrious a band of scholars as could be found anywhere.

Under the same roof there lived Julius Bernstein (the son of the family's old friend), who was at that time one of Helmholtz's assistants, and who, as professor of physiology at Halle, has since risen to be one of Germany's great physiologists. Bernstein and the Meyers fraternized much together. To this trio there was later added a fourth—Paul du Bois Reymond, then *privat-docent* in mathematics.

Meyer's work at the University was brilliant in the extreme: he headed the lists in every course. In May, 1867, when but nineteen years old, he received the Doctor's degree *summa cum laude*—which is given on but rare occasions. Bunsen immediately appointed him to an assistantship, and here he chiefly busied himself with analyses of various spring waters by methods initiated or improved by Bunsen and his pupils.

In addition to his work at the laboratory Meyer was much in demand as a coach for the doctor's examination. Yet he found time to cultivate his artistic tastes in many ways. From his earliest days he played the violin; now he began to take lessons in piano playing. The classics he assiduously cultivated, and never missed an opportunity of attending the more notable performances at Mannheim. His week ends were usually spent wandering near Heidelberg. Julius Bernstein, who often accompanied him on these excursions, tells of a pretty little incident that occurred to them on one occasion: "Towards evening, tired and weary after a day's tramping, we entered a wine cellar, and there sat down at one of the tables. A young peasant who happened to come in came up to us and asked permission to sit at our table. As we were chatting with him he fixed his eyes on Victor, stared at him for some time, and then exclaimed, 'See here, never in my life have I seen such a handsome fellow as you are.'

Just quite in this way Victor was hardly ever addressed again, but it is a fact that the ladies were all more or less in love with him."

In the late sixties, Baeyer had already established a reputation such as to attract students from all parts of the world, and it was to Baeyer's laboratory in Berlin (at the *Gewerbeakademie*) that Meyer proceeded in 1868. And what a busy and profitable place this proved to be! Baeyer himself had already begun his classic researches on indigo blue. Graebe and Liebermann had just produced alizarin artificially—the first instance of the synthesis of a plant-coloring matter. S. Marasse, B. Jaffe, E. Ludwig, and W. A. van Dorp were all helping to make the laboratory famous.

The young Meyer made more than a favorable impression, according to Liebermann's testimony: "Meyer's remarkable ability could hardly pass unnoticed. His congenial personality added but to the esteem in which he was held. He seemed to have read everything, and his memory was simply phenomenal. . . . Many obscure references that at that time were rather difficult to locate could easily be traced by consulting Meyer. He could usually tell you not merely the volume but the very page."

During the three years that Meyer remained here he published several important papers, among which may be mentioned his contributions on the constitution of camphor, of chloral hydrate, and of the benzene ring.

Towards the end of 1870, at Baeyer's recommendation, Meyer was appointed professor extraordinary at the Stuttgart Polytechnik, of the chemical laboratory of which H. v. Fehling was the director. Here the twenty-three-year-old professor, who had never been *privat-docent*, was put in charge of the organic chemistry department.

Stuttgart proved an incentive to renewed activity. Here he announced his discovery of the nitro compounds of the aliphatic series—his first really lasting contribution to the advancement of the science.

Though little burdened with routine at Stuttgart, Meyer was sorely tempted to accept a first assistantship at the University of Strassburg, offered him by Baeyer, who was about to take charge of the chemical institute there. On the one hand, there was the opportunity of once again coming in contact with the great master

mind; on the other hand, he was to be put in charge of the analytical department, and this meant running around the laboratory and attending to the wants of the students the greater part of the day. In Stuttgart he therefore remained—till one day President Kappeler, of the Zürich Polytechnik, chanced to walk into his lecture-room. Kappeler was so impressed with the young man's ability that he immediately offered Meyer the vacant professorship of chemistry at Zürich. And so at twenty-four Victor became a full-fledged professor *ordinarius!*

This appointment Meyer celebrated in a highly appropriate way: he became engaged to the companion of his youth, Fraulein Hedwig Davidson.

The Zürich laboratory was divided into two parts, the analytical and the technical, and of the former Meyer had charge. His predecessor was Wislecenus, who had accepted a call to Leipzig. Bolley had control of the technicological side. With Bolley, as well as with Eduard Schar, the professor of pharmacy, and Ernst Schulze, the professor of agricultural chemistry, the newly-appointed instructor fraternized much. The researches that had been started at Stuttgart were now renewed with the utmost vigor. In the beginning all did not go well. A mercury compound of nitromethane which Rilliet, his private assistant, had prepared, exploded, with serious injury to Rilliet. Wurster was brought from Stuttgart to replace him, and Meyer found him a competent substitute. "I have given him rooms in the laboratory," he writes: "this is of the utmost importance, as thereby he can do twice as much work. He is very conscientious—so much so, that I think I shall send for another one of my Stuttgart pupils."

Satisfied as he was with the assistants he imported, Meyer was far from satisfied with the assistants he found, or with the cool reception accorded him by the students. In Stuttgart he was the idol of his pupils; here the men had little sympathy with one so much taken up with the theoretical aspect of the subject. "One single publication on some cheese preparation makes one far more celebrated in Switzerland than one thousand discoveries in the field of pure organic chemistry," he writes bitterly. But the day was to come when the Swiss were to venerate him, and the day was also to come when Meyer would love his Zürich students and the Zürich atmosphere.

From the very first he had his hands full. "I am very busy," he writes, "as you can conclude from the following: I devote eight hours to lectures in organic chemistry, two to lectures on analytical chemistry, two to metallurgy (in place of Kopp, who is in Vienna), and besides this I have to superintend Kopp's as well as my own laboratory." But this did not prevent him from pursuing his research work. In the month of July he records the synthesis of diphenyl-methane from benzoyl alcohol and benzene. This compound, which melts at 26° C., Meyer placed on his writing table, and used it in place of a thermometer. At ten in the morning, if the substance was in a molten state, the Herr professor would announce that weather conditions made it impracticable to pursue any work in the laboratory; and then professor and students would go bathing. On one of these occasions Meyer rescued one of his assistants, Michler, from drowning.

But recreation played but a small part in the Zürich life. Apart from the regular students there were (in 1876) twelve men working for their doctorate, in addition to Meyer's four assistants, who had already passed that stage, but who were busier than any of the candidates creating new compounds. The nitro compounds of the aliphatic series, the first piece of classical research with which the name of Meyer is associated, were engaging the attention of the youthful professor; but even at that time he made excursions into the realm of indigo chemistry (the artificial production of which he hoped to solve in one week!) and discussed Van't Hoff's views on optical activity and the asymmetry of the carbon atom.

With Baeyer, the great master, and with Graebe and Liebermann, Meyer carried on a brisk correspondence, the letters dealing chiefly with views on current scientific topics. In 1876 his elder brother obtained a position near Zürich and Victor's delight knew no bounds. Gustav Cohn, the economist, and Eduard Hitzig, the psychiatrist, were about this time appointed professors at the University. Graebe himself, who had been in delicate health, resigned from his Königsberg position and came to Zürich to join the happy crowd. But for a rather unpleasant polemic with Ladenburg (Meyer later dubbed this episode the *Ladenburg-Fieber*) which tended to undermine Meyer's delicate constitution, there was nothing at this time to mar the even tenor of the young man's life. He had just begun his second classical

work: his method of determining vapor density. We find him writing to Baeyer asking for some methyl anthracene, a substance which by analysis can hardly be differentiated from ordinary anthracene, but which can easily be identified by the vapor density method.

In the spring of 1876 Meyer received a call from the Königsberg authorities, but by this time he had come to like Zürich and was loath to leave it. As an inducement to remain, and in appreciation of his services, Kappeler had Meyer's salary increased by 1500 francs a year. Not so very long after this a vacancy occurred in Erlangen. The rumor had gone forth that Meyer would be offered the position, and this came to the ears of the president. Without waiting to hear from Meyer, Kappeler took the initiative by informing him that the wish of the governing body to have him remain in Zürich was so earnest that they were willing to make his position tenable for life, provided he would decide to stay (Meyer held it on a ten-year contract), and that they would further increase his salary by 1000 francs. "As I had no desire to go to Erlangen," Meyer writes to Baeyer, "I gave him the assurance with pleasure."

The miscarriage of one of his experiments before the student class made him hit upon what is conceded to be his most brilliant discovery—thiophene. "The analyses," he writes to Baeyer, "have shown the compound to have the formula C_4H_4S. It boils at 84° C. How should it be named? Kindly help me. I do not like such a name as thiofurfuran. . . . How about indogen? . . . or indophenin? or thiochrom, krytan, krýptophan? I would like to get hold of a name that would please you, too. Possibly the Frau Professor would like to take part in this." Thiophene was the name finally selected, and this became the mother substance of a group of compounds almost as extensive as benzene itself, which the genius of Meyer introduced into organic chemistry.

In January, 1884, in the company of Professor Bluntschli, the architect, Meyer undertook a journey through Austria-Hungary, with the view to examining the various chemical laboratories there. Their journey lay over Munich, and here the first stop was made. "We have already been in Munich and Graetz," he writes "and in both places we had a most delightful time. In Munich I spent a lovely time with Baeyer, Otto Fischer, and

König, and one delightful musical afternoon with the Heyses." (Here he refers to Heyse, the poet and novelist.) Again: "The new buildings in Vienna defy description. The Parliament, the Guildhall, the University, and the Hofburg Theatre constitute a section beside which the Place de la Concorde in Paris fades into insignificance. In addition they have the recently-constructed museums by Semper, which are the finest examples of Renaissance architecture. I witnessed a performance of the *Walküre* and the second part of *Faust*. I also saw my old flame, the actress Lucca. You can imagine how happy I was to see her again after thirteen years of absence. She is as beautiful as ever, time not seeming to have altered her."

In July, 1884, Hübner, the Göttingen professor, died. Meyer's friend Klein, who informed him of this, also told him that he was a likely candidate. The thought of having to leave Zürich was quite unbearable. What had he not accomplished during these thirteen never-to-be forgotten years! But, then, to step into the world-famed Göttingen school—that had also to be considered.

Meyer had not yet reached his thirty-sixth year. He had to regard the call to Wöhler's old establishment as the highest compliment that could be paid to him. Indeed, the compliment proved a higher one than even he expected, for he was not to be selected from a group, but none others were even to be considered.

During the last days of the year 1889 Meyer proceeded to Bonn to undergo an energetic cure: a sort of massage and electrical treatment combined. He writes: "For fourteen days I lived in the strictest incognito, going under the name of Professor Meyer, of Berlin. Since a week ago I have given this up and am now with Wallach and Kekulé daily. To see Kekulé once again and to speak to him does one's heart good. You will not consider me vain when I tell you that it was delightful to hear him say to me that he considered me the foremost among the chemists of the younger generation. Wallach is a splendid type of fellow. He visits me daily. He has no easy life of it. What a pity that he cannot go to Zürich! I suppose you have heard that Hantzsch has been nominated to succeed me. I am glad to see that both Kekulé and Wallach approve of Kappeler's choice. Wallach has completed a wonderful piece of work on the terpenes which must surely become epoch-making."

Meyer left Bonn in indifferent health and after a short stay in

Zürich proceeded to the Riviera with his parents. Here he felt himself slightly better, but not very much so. "Italy and the Riviera are very nice, but only for the one who is in a position to enjoy her beauties," he writes. "In my case, where I dare not go beyond one-half hour's distance from the house, the mountains call in vain."

In this condition Meyer proceeded to Göttingen. He was comforted to a large extent in that his excellent assistant, Sandmeyer, accompanied him for the summer semester. Sandmeyer, one of Meyer's "discoveries," is to-day known wherever chemistry flourishes. He started as a mechanic in Meyer's laboratory, but soon gave this up to devote all his time to chemistry.

Meyer left Zürich without being able to take leave of his students, but some months later he returned to attend the seventieth birthday of Kappeler. At the *Kommers,* which was given in the old man's honor, Meyer was among the speakers. Professor Goldschmidt thus describes the scene: "I see him (Meyer) even now before me as he spoke to the students at the *Kommers* in the evening. The 'Züricher Polytechnikers' have, as a rule, but little opportunity of knowing the professors outside their special faculty, and have therefore but little interest in those who are not their own teachers. As Victor Meyer's slender form appeared on the platform, and as his bright blue eyes glanced around the assembly, there broke forth a shout of welcome from all—engineers, machinists, architects, as well as from his own students, the chemists—to be ended in a whirlwind of applause at the close of a speech, sparkling and witty as ever."

Meyer's reception in Göttingen was all that could be desired. His inaugural lecture created a furore ("*es war zum Brechen voll,*" he writes), and he was well pleased with so auspicious a beginning. Besides, the other men on the staff were such as any head of a department could well be proud of. C. Polstorff, K. Buchka, R. Leuckardt, P. Jannasch, and L. Gattermann were among the regular forces. Then there was the old attendant Mahlmann, whom the students of Wöhler still remembered as a marvel in glass blowing. And, finally, Sandmeyer, Stadler, and several other Zürich men completed the list.

The scientific work inaugurated here was in the main a continuation of what had previously been started elsewhere. That wonderful thiophene, which seemed to be the starting point for

as many derivatives as benzene itself, was still a keen subject for study in his laboratory. The material along these lines accumulated to such an extent that Meyer found himself warranted in publishing a book on these sulphur compounds. Vapor density determinations—a subject which had agitated him even early in his Zürich career—were being followed up with unslackened zeal.

But Meyer was never so engrossed with his own work as not to keep abreast of the work which others in the field were doing. Thus we find him engaging in a friendly polemic with Baeyer on the latter's views as to the constitution of benzene. Stereoisomerism—a term coined by Meyer—dealing with configuration in space, a subject then in its infancy, also engaged his attention, and he early applied Van't Hoff's views to explain several perplexities, such as the configuration of hydroxylamine and isomeric oximes of unsymmetrical ketones. Here we see the Professor no less proficient in the field of speculation than in that of experimentation.

Feeling the need of a comprehensive treatise on organic chemistry, which neither the German nor any other language supplied, Meyer, in collaboration with his assistant Jacobson, started his famous text-book. To this day it has not its peer. Those who have had occasion to do any extensive work in this branch of the science know well enough how indispensable a part of their equipment this book is. Unfortunately the senior author did not live long enough to see the work in its completed form (it ultimately appeared—still incomplete—in two bulky volumes).

Much as the nature and extent of the research work adds to the renown of an institution, certain other factors tend to have no small influence. When Meyer came to Göttingen the size and equipment of the laboratories were far from what could be desired, and one of his stipulations was that this state of affairs would soon be altered. With a willingness which could result only from the esteem in which Meyer was held, the authorities appropriated a sum sufficient to build a new laboratory, and gave him complete charge of supervising its construction. Of course, this took up much time, but as this was to prove the tools of the carpenter, and realizing how much the finished product is dependent upon the quality of the tools employed, Meyer threw

himself into it with a wholeheartedness which was characteristic of everything he undertook.

Another step in the direction of increasing efficiency was the formation of the Göttingen Chemical Society. The number of research men had risen to such a height—at this time there were 105—that Meyer readily foresaw the advantage of organizing a club where these men could congregate and discuss current topics. At these meetings the students would give accounts of the progress of their latest investigations, and professors and students would engage in friendly criticism. The *esprit de corps* thus created was little short of wonderful.

The one source of great worry to Meyer as well as to his dear friends was the state of his health, which at best was but indifferent. Here in Göttingen he had formed a very intimate friendship with Ebstein, a well-known professor in the medical faculty, and, fortunately for him, Ebstein was untiring in his efforts. In 1888, when Meyer suffered a bad attack of diphtheria, only his friend's constant attention saved him. Ebstein prescribed no end of rest cures. These were well enough in themselves, but, as they so often clashed with work in the laboratory, Meyer fretted not a little. However, feeling that it was a question of life and death, he usually yielded.

It was on one of these recuperation tours that Meyer revisited his old Zürich. His reception by faculty and students left no doubt as to the way they regarded their old professor. But he had already had a proof of this shortly after he came to Göttingen. Then his Zürich scholars sent him an address which he described as "*so etwas schönes habe ich noch nicht gelesen und auch noch nicht gesehen.*"

The summer vacations were usually spent in Heligoland by the sea. Here, in company with his friends, Liebermann, Tollens, Ebstein, and occasionally Kirchoff, the weeks were passed in recuperation and interchange of views.

In the fall of 1888 his quiet life gave place to days of great agitation.

On November 11 he writes to his brother: "Confidential! Yesterday I received an official communication from the ministry offering me the professorship in Heidelberg in succession to Bunsen. They are ready to do anything I want them to do. But not a soul must know of this till next Thursday. On that day the

new chemical building will be officially opened, and were this news to leak out then, it would cause a great scandal. What shall I do, unlucky man that I am! The greatest piece of good fortune in the world, and yet here I am—a most dissatisfied beggar." To Baeyer he writes: "I must write to you in the very first place. I am not far wrong when I surmise that you have had a great deal to do with the honor that has come to me. My debt of gratitude to you is forever on the increase. The Minister of Education writes that the Faculty and Senate have nominated me *unico loco*, and that Bunsen was particularly desirous of seeing me succeed him."

In Berlin, where negotiations were begun, Althoff, the minister, was as bent upon retaining Meyer—at least in Prussia—as the Heidelberg authorities were bent upon getting him. He held out the assurance that Meyer would be the logical successor to Hofmann in Berlin, as Helmholtz and the majority of the faculty there had declared themselves in his favor. "I brushed all this aside," writes Meyer, "and told Althoff that I hoped Hofmann would write a nice obituary notice of me in the *Berichte*." Not even the title of *Geheimrat*, which was bestowed upon him at this time, could influence him. "On the envelope you address me as *Geheimrat*," he writes to his brother. "That, of course doesn't matter, and yet it troubles me. I have strictly forbidden any of my assistants to apply that title to me. 'Professor' is far more to my liking, and that they shall call me, as they have hitherto done."

Urged by Bunsen, Meyer finally decided for Heidelberg. "I am the happiest and yet the most wretched of men," he writes.

Before proceeding to asume his duties in Heidelberg he spent several delightful days in Bordighera. Here were Baeyer, Emil Fischer, Wallach, and Quincke, "the masters of them that know" in chemistry.

To Heidelberg Meyer took as his assistants Jannasch, Gattermann, Jacobson, Auwers, and Demuth. At this day when one reads these names one cannot but help admiring Meyer's wonderful judgment of men. Every one of these five has since made an enviable name for himself.

"I saw him in Heidelberg in the spring of 1891," writes Thorpe,[42] "when he was busy with the enlargement of the old laboratory, and it was with a glance of pride—a pardonable pride—that he pointed out the places where he and I had worked

with 'Papa' Bunsen. . . . It was strange, too, to hear the sound of children's voices and their laughter, and the bustle of servants in what was formerly the silent, half-deserted rooms overlooking the Wredeplatz; and stranger still to me was it, as we together called upon Bunsen, sitting solitarily in his rooms overlooking the Bunsenstrasse, to behold the meeting and to listen to the greeting of these two men—the memory of whose names and fame Heidelberg will cherish so long as Heidelberg exists."

At forty-one Meyer found himself head of—what then was—the most famous chemical school in the world. For many years Bunsen had been looked upon as the Nestor of the science. The most promising students all flocked to Heidelberg to sit at the feet of the great master. Almost every university chair of chemistry of any pretensions was filled by one of Bunsen's pupils. Yet of all of them Bunsen looked upon Meyer as the most brilliant, and it was because of that that he was so eager to have Meyer succeed him.

As in Göttingen so in Heidelberg, Meyer continued researches long before begun. These were, however, supplemented by one important addition: a study of conditions determining both the gradual and explosive combustion of gaseous mixtures, and this new phase of his labors may be regarded as the outstanding feature of his Heidelberg tenure of office.

All would have been well but for his physical sufferings. These re-commenced soon after he came to Heidelberg, and they scarcely left him till the day of his death. Early in the morning of August 8, 1897, he took his own life by swallowing some prussic acid. On the table he left this message: "*Geliebte Frau! Geliebte Kinder! Lebt wohl! Meine Nerven sind zerstört, ich kann nicht mehr.*" At the early age of forty-nine, when in the full bloom of his powers, this remarkably gifted man passed away.

. . . .

From the reports which have come to us it would seem that Meyer's qualities as a teacher were rivalled only by his powers as an investigator. Mention has already been made of his histrionic talents; these were put to effective use in later days as professor. His extraordinary command of language, spoken in a well-modulated voice, and coupled with a well-nigh unrivalled knowledge of his subject, went far to assure success. In addition, Meyer's laboratory technic, one of his precious assets, stood him in excellent stead when experimentally illustrating his lec-

tures—and his lectures were always copiously illustrated by experiments, in the preparation of which no pains were spared.*

Nor as a man did he fall short. Sympathetic by nature, generous almost to a fault, always eager to acknowledge the labor of others, with not a taint of jealousy in his make-up, full of a hearty optimism which made him a congenial companion, a splendid *raconteur,* an excellent after-dinner speaker, a violin-player of no mean calibre—these qualities endeared him to all. His friends, Bunsen, Kopp, Erlenmeyer, Baeyer, Graebe, Kekulé, Liebermann, Fischer, etc., respected him not only as an eminent colleague, but loved him as a man of worth.† His house was a centre not merely for scientific, but literary and artistic notables. At these gatherings his charming wife and four daughters did much to contribute towards a delightful evening.‡

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* "I well recollect that the word most frequently used in Zürich in defining the opinions of Victor Meyer's students of his lectures was 'brilliant!' (Watson Smith). "What particularly struck me about his lectures was their finished style. He made fairly constant use of notes, speaking with great rapidity. Yet his treatment of the subject was very clear, and his language perfect. The experiments were always well prepared and exceptionally successful. Indeed, his lectures were most popular. . . ." (John I. Watts.) See E. Thorpe.[42]

† *Ich muss Euch doch sagen, wie entzückt ich wider von allem bin: Berlin, Halle, München. In München war es ganz herrlich mit Baeyers, Fischers, und dem anderen. Baeyer ergriff einmal bei Tische das Glas um mit Emil Fischer und mir Schmollis zu machen, denkt nur, der liebe Mann! Es brachte uns momentan in förmliche Verlegenheit, denn natürlich brauchten wir mehrere Tage, bis wir uns daran gewöhnen konnten, ihn ungeniert Du zu nennen."* (Victor Meyer, in a letter to his brother, October 17, 1883.)

‡ "*Die jugendliche Gestallt, der fein geschnittene, geistreiche Kopf, das seelenvolle blaue Auge, der Wohlklang der Stimme nahmen schon äusserlich Jeden für ihn ein.*" (Liebermann.[41])

"Young, handsome, well dressed—for a German professor—with a quick wit and a genial manner, he was a welcome addition to any gathering." (John I. Watts.)

"No one was more popular at these gatherings (the Chemical Society at Heidelberg) than Meyer. His nimble mind and retentive memory, his gift of ready speech, his sense of humor, and genial manner combined to make it pleasant to listen to him, no matter whether he was, in accordance with the rules of the society, called upon to give an account of some work which had just been published, or whether he was discussing and criticising a communication from a fellow-member." (Thorpe.[42])

Meyer was not one of those professors who shrink from popularizing their science. He frequently wrote for the *Naturforcher, Naturwissenschaftliche Rundschau, Deutsche Revue, Deutsche Warte.* Even in Harden's *Zukunft* we find an article on Pasteur in which the attempt is made to explain the asymmetry of the carbon atom to a lay public. Nor were his activities confined to strictly scientific subjects. In pure *belles-lettres* he published "Wanderblättern und Skizzen Aus Natur und Wissenschaft" and "Märtztage im Kanarischen Archipel."

At the time of his death Meyer was president of the German Chemical Society, Emil Fischer being the vice-president. In 1888, when the new building at Göttingen was finished, the title of Geheimrath was bestowed on him. He was also a member of the *Akademien der Wissenschaften zu Berlin, München; die Gesellschaft der Wissenschaften zu Upsala,* and *Göttinger Gelehrte Gesellschaft.* From the Royal Society of London he received the Davy Medal, and the University of Königsberg granted him the degree M.D. (Hon.).

II. HIS WORK.

Victor Meyer, together with his students, published several hundred papers during his short but very strenuous career. It becomes, of course, quite impossible to review each of these separately. However, a fair idea of the nature and extent of Meyer's work can be given without very much difficulty, for, however diversified and disconnected his writings seem when some of the titles of his papers are glanced at, in reality there is a very remarkable unity existing among them. Brushing aside his preliminary skirmishes into the constitution of chloral hydrate and that of camphor—work done primarily to familiarize himself with the research methods in organic chemistry—we see that, starting with his celebrated investigation of the nitro compounds of the aliphatic series, all his subsequent work was the expansion of a solid foundation. The action of nitrous acid on the aliphatic nitro-compounds led to the nitrolic acids; these again, with their oxim-like structure, paved the way for the study of hydroxylamine and the oximes. Attempts to establish the molecular formulæ for some of his compounds having a high boiling-point, and which could be prepared in relatively small amounts, led to his vapor density method, which in turn gave rise to an

almost endless series of pyrochemical investigations. True, in this chain of well-connected links thiophene finds no place. But then the discovery of thiophene had its source in a lecture experiment which proved a failure!

The Nitro Compounds of the Fatty Series.

A characteristic of aromatic compounds is the ease with which they form nitro bodies of the type $R.NO_2$, where nitrogen is directly attached to carbon. Prior to Victor Meyer's time but few nitro compounds of the aliphatic series were known, and these had been prepared by special methods. No general method of preparation had been devised. While still in Stuttgart, Meyer's attention was drawn to the subject, and there, after many trials, he obtained the key to the difficulty. He found that when an equivalent quantity of amyl iodide was added to dry *silver nitrite* (and the use of the silver salt here is all-important), the mixture heated for some time and then fractionally distilled, the major portion came over at 150° to 160°. Analysis showed this product to possess the formula $C_5H_{11}NO_2$. This reaction, therefore, proceeded according to the equation: $C_5H_{11}I + A_gNO_2 = A_gI + C_5H_{11}NO_2$. But this compound could have one of two formulæ: either $C_5H_{11}.ONO$ (a nitrite, where the nitrogen is combined with the oxygen, and *not* directly with carbon), or $C_5H_{11}NO_2$ (a *nitro* compound). Now the nitrite was a well-known compound which had been prepared by the action of nitrous acid on amyl alcohol, and which had a boiling-point of 96° C.—more than 55° lower than the oil obtained by Meyer. Clearly, then, we were here dealing with the other modification.[1]

This Meyer established beyond dispute in his following two publications.[2, 3] In the aromatic series a nitro compound is readily reduced to its corresponding amine ($R.NO_2 \rightarrow R.NH_2$). This was found to be just as true for these aliphatic compounds.

On the other hand, their isomers, the nitrites, when reduced, yielded alcohol and ammonia. Again, the nitrites could easily be hydrolyzed to alcohol and nitrous acid, whereas sodium hydroxide did not decompose the nitro compounds.

A systematic investigation of these nitro-paraffins was now undertaken. Meyer had originally selected the amyl compound because he feared that, ethyl nitrite being very volatile (boiling-

point 16° C.), its nitro isomer would probably prove to be so too, and hence there would be great difficulty in separating the two.* But nitro-ethane was found to boil at 113° C., and the methyl, propyl, and butyl compounds were prepared in quick succession.

A study of the properties of the nitro-paraffins revealed interesting facts. They proved to be soluble in sodium hydroxide, and were reprecipitated with acids, thereby showing them to be acidic in nature. One of their hydrogen atoms could be replaced by sodium ($C_2H_5NO_2 \rightarrow C_2H_4Na \,.\, NO_2$). The halogen compounds, such as $R \,.\, CHClNO_2$ and $R \,.\, CHBrNO_2$, also showed acidic properties.[5, 6]

The effect of nitrous acid on nitro-paraffins was of the most surprising kind. Meyer found that when an excess of sodium nitrite was added to sodium nitro-ethane, and dilute sulphuric acid carefully poured into the mixture, a blood-red color developed: $C_2H_5NO_2 + HNO_2 = H_2O + C_2H_4N_2O_3$.[4] Meyer later obtained the same reaction by the action of hydroxylamine on dibrom-nitro-ethane: $CH_3 \,.\, CBr_2NO_2 + NH_2OH =$ $CH_3 \,.\, C\Big\langle{}^{NO_2}_{N.OH} + 2HBr$, thereby showing these *nitrolic acids* to be nitro-oximes—a reaction which paved the way for the whole field of oxime compounds.

By the substitution of secondary nitro-paraffine $\left({}^{R}_{R'}\!\!>CH\text{-}NO_2\right)$ for primary compounds (RCH_2NO_2), an intense blue color was obtained: $((CH_3)_2CHNO_2 + HNO_2 = (CH_3)_2C\Big\langle{}^{NO_2}_{NO} + H_2O)$, giving rise to *pseudo-nitroles*.[4, 7]

Finally the tertiary nitro-paraffins $\left(\begin{matrix}R\\R'\\R''\end{matrix}\!\!>CNO_2\right)$ did not react with nitrous acid.

Here, then, was an excellent means of differentiating between the three classes of nitro compounds.[7]

As in the nitro-paraffins, a whole homologous series of nitrolic acids and pseudo-nitroles were carefully investigated.

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* The method with silver nitrite gives rise to both modifications, but, since the nitro-paraffins have a much higher boiling-point, their separation becomes relatively easy.

Oximes.

We have seen that the character of the nitrolic acids was elucidated by the preparation of one of their typical members from dibrom-nitro-ethane and hydroxylamine. Meyer further studied the effect of hydroxylamine on unsymmetrical dichloracetone in the expectation of getting a product similar to ethyl nitrolic acid; namely, $CH_3COCH:NOH$. But the results obtained were very different.

In his particular experiment hydroxylamine hydrochloride, dissolved in water, was mixed with an equal quantity of sodium hydroxide, and dichloracetone added. After 24 hours the product was acidified and extracted with ether. On evaporating the ether, white crystals remained. These were recrystallized from water and alcohol. Analysis showed the compound to correspond to $C_3H_6N_2O_2$. This compound, then, contained not one but *two* atoms of nitrogen—which, of course, immediately excluded the simple nitrolic form. The reaction, Meyer suggested, could be most simply explained as follows:[8]

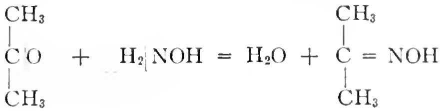
$$\begin{array}{llcll}
\mathrm{CH_3} & & & & \mathrm{CH_3}\\
| & & & & |\\
\mathrm{C\;O} & +\ \mathrm{H_2\,NOH} & = & \mathrm{H_2O} + 2\mathrm{HCl} + & \mathrm{C = NOH}\\
| & & & & |\\
\mathrm{CH\;Cl_2} & \quad\mathrm{H_2\,NOH} & & & \mathrm{CH{=}NOH}
\end{array}$$

a reaction which was somewhat supported by the fact that the compound could also be obtained by treating nitrosoacetone with hydroxylamine:

$$\begin{array}{llcll}
\mathrm{CH_3} & & & & \mathrm{CH_3}\\
| & & & & |\\
\mathrm{C\;O} & +\ \mathrm{H_2\,NOH} & = & \mathrm{H_2O} + & \mathrm{C = NOH}\\
| & & & & |\\
\mathrm{CH_2NO} & & & & \mathrm{CH_2NO}
\end{array}$$

Thus was the first oxime prepared. Meyer immediately turned his attention to the action of hydroxylamine on aldehydes and ketones; that is, substances containing the group $=CO$. Here he anticipated that the oxime formation would prove a general one, and his expectations were more than realized. When acetone was added to hydroxylamine hydrochloride mixed with an equivalent quantity of 10 per cent. sodium hydroxide, and the mixture allowed to stand for 24 hours, the odor of acetone disappeared. The solution was extracted with ether, and the ether evaporated, leaving white prismatic crystals. Analysis and vapor density

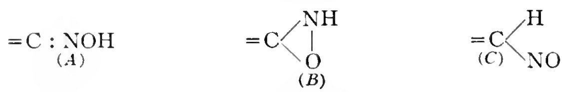
determinations gave the formula C_3H_7NO:[9]



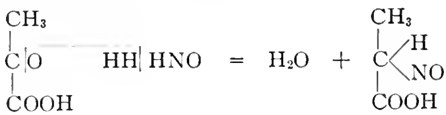
Acetaldehyde was shown to behave similarly.

The further work of Victor Meyer and his pupils showed that the reaction was quite a general one.[10]

If we now turn to the question of the constitution of these oximes we find that his work is a clear extension of his investigations into the constitution of the nitrolic acids. It was clear enough that hydroxylamine could convert the $=C:O$ group into $=CNHO$, but what structure was to be assigned to this $=CNHO$? Three possibilities presented themselves:



In the first place, was hydroxylamine capable of giving rise to a true nitroso compound such as (*C*)? In order to test this, Meyer prepared α-nitrosopropionic acid, $CH_3 . CH(NO) . COOH$, from methylacetoacetic ester and sodium nitrite in sodium alcoholate, and then he showed that this same compound could be obtained from pyroracemic acid with the help of hydroxylamine:[11]



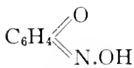
Of course, this might be taken as evidence that hydroxylamine can give rise to true nitroso compounds. However, further work—such as the failure to get nitroso compounds by the action of nitrous acid on the phenylated benzyl cyanide $(C_6H_5)_2CHCN$, which should have given $(C_6H_5)_2C(NO)CN$—tended to shift him to the viewpoint that most nitroso compounds, if not all, are, in reality, isonitroso, or oxime-like substances.[12] *

There was still the possibility that the compound had a formula such as is shown under (*B*). Meyer prepared the benzyl

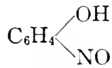
---

* "*Die Versuche zeigen . . . die unüberwindliche Abneigung welche in der Natur gegen die Bildung wahrer Nitrosokörper besteht.*"

derivative of acetoxime, which could be represented either as $\underset{\text{N.OC}_7\text{H}_7}{\text{CH}_3\text{.C.CH}_3}$ (corresponding to (A)), or $\underset{\text{O}-\text{N.C}_7\text{H}_7}{\text{CH}_3\text{.C.CH}_3}$ (corresponding to (B)). The former, on reduction, should have yielded benzyl alcohol and ammonia, the latter benzylamine. The products obtained showed that formula (A) was the correct one.* However, the situation was much complicated by Goldschmidt's discovery (in Meyer's laboratory) that quinone and hydroxylamine produced a compound (a) in every way identical with Baeyer's nitrosophenol, obtained by the action of nitrous acid on phenol



Quinoxime
(a)



p-nitrosophenol
(b)

(b):[13] and to this day the question of the constitution of quinones is a debatable one.†

Of the many interesting properties brought out by a study of these oximes, mention may be made of Meyer's observation that, whereas the aldoximes with acetyl chloride yield cyanides: $CH_3 . CH : N . OH = CH_3 . CN + H_2O$, ketoximes are converted into acetyl derivatives:

$$RR'C{:}N.OH + CH_3COCl = RR'C{:}N.O.COCH_3 + HCl$$ [14]

With his friend Ernst Schultze, who was at the time professor of agricultural chemistry at the Zürich Polytechnik, Meyer investigated the effect of hydroxylamine on the growth of plants.[15] The importance of nitric acid and ammonia in nitrogen assimilation was well known. Hydroxylamine, argued the authors, might be regarded as fitting with the scheme

$$HNO_3 \xrightarrow{\text{reduction}} NH_3 \xrightarrow{\text{oxidation}} NH_2OH$$

though no one had hitherto been able to show its presence in plant extracts. However, they found that in the presence of hydroxylamine plants died within five to six days—unlike nitric acid or ammonia, in the presence of either of which they thrived.

* As a matter of fact, evidence has since been deduced to show that the oximes can exist in either modifications,—that they are really tautomeric, readily changing from one to the other. See, for example, A. F. Holleman,[43] p. 329.

† See, for example, V. von Richter,[44] vol. ii, pp. 152, 167.

Yet their concluding note was not one of discouragement: "*Es sei daran erinnert dass z. B. Peptone eine giftige Wirkung ausüben, wenn man eine Lösung derselben in der Adern eines Thieres einspritz, während sie doch zugleich im Thierkörper als notwendige Zwichenprodukte bei der Verdauung entstehen.*"

Method of Determining the Vapor Density.

Early in his career Meyer, as every other organic chemist, had to make constant use of vapor density determinations in order to arrive at the correct formula of a substance. The methods then in use had important drawbacks, and it was the attempt to obviate these shortcomings that finally resulted in his now well-known vapor density apparatus.

The first paper to be published on the subject appeared in 1876,[16]—some four years after the publication of his first paper on the nitro-paraffins, and about six years before his discovery of the oximes. Meyer readily recognized the accuracy of Hofmann's method, then much in vogue, which in principle was similar to that of Gay-Lussac's; namely, measuring the volume of a weighed quantity of the substance which had been vaporized. But the fact that mercury was here used at once excluded its use for substances with boiling-points higher than that of this element. In that case Dumas's procedure, as further modified by Deville, Troost, and Bunsen—in principle, the weight of a known volume of vapor—was resorted to. But here again at least three grammes of the substance had to be at one's disposal—which in quantity was often far more than the total output of a newly-discovered product, often enough isolated under the most difficult conditions. Meyer, therefore, in devising his first modification had in mind these two important points: the amount of substance needed should be small (about 0.5 Gm.), and the method should be available for high temperatures. Wood's metal, an alloy consisting of bismuth, lead, tin, and cadmium, was finally adopted in place of mercury. The advantages of this alloy were several: it melted at 70° C., so that one could work with it almost as conveniently as with mercury; again, most organic vapors did not affect it, and any impurities could be easily removed; finally, it could be used for temperatures as high as the boiling-point of sulphur (444° C.). The vessel, filled with Wood's metal and the substance under examination, was placed in a bath of boiling

sulphur, and the volume of vapor, and from that the vapor density, determined by loss of weight:* "*An Stelle des für derartige Zwecke bisher einzig angewandten Quecksilbers eine nicht flüchtige Substanze also Sperr-flüssigkeit anzuwenden, eine kleine, genau abgewogene Probe der Substanz (ca 0.05 Gm.) in einem, von der nicht flüchtigen Flüssigkeit ganz erfüllten Gefässe zu verdampfen, und aus dem Gewichte der verdrängten Sperr-flüssigkeit das Volumen des Dampfes zu ermitteln.*"

The values obtained for substances of known molecular weight compared favorably with those calculated. For example, diphenyl gave a vapor density of 5.33; calculated for $C_{12}H_{10}$ = 5.23: diphenylamine gave 8.49; calculated for $(C_6H_5)_2NH$ = 8.47: methyl-anthracene, so closely resembling anthracene in properties, showed an appreciable difference in vapor density:

	Found	Calculated
Anthracene	6.24	For $C_{14}H_{10}$, 6.15
Methylanthracene	6.57	For $C_{15}H_{12}$, 6.63

Anthraquinone was tried to test the effect of Wood's metal on an oxygen-containing substance, and one capable of being reduced by zinc dust; found, 7.22; calculated for $C_{14}H_8O_2$, 7.19. Neither did halogen compounds present any difficulty; *para*dibrombenzol—found, 8.14; calculated for $C_6H_4Br_2$, 8.15.

A year later Meyer published a modification of his method, extending it to substances of a lower boiling-point.[17] Here, instead of using sulphur vapor for heating purposes, the vapor of one of several liquids—depending upon the temperature required —was employed: water, aniline, ethyl benzoate, amyl benzoate, or diphenylamine. The apparatus here used was the one subsequently adopted in his displacement method, only in this case the volume of gas, instead of being measured, was still obtained by the difference in (loss of) weight before and after the experiment. Into a U-tube arrangement of some 35 c.c. capacity (*A*), so constituted as to be comparatively wide on one side and narrow on the other, about 0.1 Gm. of substance was introduced. This was weighed and filled with mercury. The wider end, tapering in a capillary tube, was now sealed off, the vessel again weighed, and then lowered into a narrow glass tube to which was fused a cylindrical vessel—precisely the one used to-day. Surrounding the glass

* For details see the original paper.[16]

tube was a wide glass cylinder closed at the lower end, and containing a liquid of a higher boiling-point than the substance under examination. This liquid was now heated to its boiling-point. The substance in (*A*) was, of course, vaporized, and a certain quantity of mercury was thereby forced out. After this ceased, *A* was taken out, cooled, and weighed. The vapor density could then be determined after correcting for temperature, pressure, and length of mercury column in (*A*).

His second modification, where the vapor of the examined substance displaces an equal volume of air, which is measured,[18] is so well known that no description of it need be given here.* The primary object of this modification was to make the method suitable for substances that are attacked by mercury and Wood's metal. The only data here necessary are the weight of substance, volume of displaced air, room temperature, and barometric pressure. The temperature of vaporization is not needed, since, all gases being equally influenced by temperature, the volume of the displaced air is the same at room temperature as the volume of the vapor would be at that temperature.†

The apparatus was further improved and extended in several ways.[19] The rather long and wide delivery tube connecting the main apparatus with the eudiometer was replaced by a short capillary tube, thereby obviating fluctuations in temperature and pressure. The adaptability of the method for substances boiling above 300° C. was assured by the use of a bath of molten lead. Later, in his pyrochemical investigations, where exceedingly high temperatures were often necessary, Meyer constructed his apparatus entirely of porcelain, and even of platinum, and heated it in a furnace.

Meyer's well-balanced mind and intensely honest disposition never allowed him to overestimate any of his results. This is well illustrated in one of his supplementary papers on vapor density.[20] Describing how extensively his method had supplanted others ‡ and adding, with all modesty, some of the many compli-

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* Consult any text-book of organic or physical chemistry; for example, W. H. Perkin and F. S. Kipping,[45] p. 41; or J. Walker,[46] p. 201.

† "*Weder der Inhalt des Gefässes, noch die Versuchstemperatur in Betracht kommt, da ja das Dampfvolum immer in Gestalt eines ihm gleichen Luftvolumens bei Zimmertemperatur gemessen wird.*"

‡ See Beilstein,[47] p. 16.

ments which had been paid him regarding it,* he yet goes on to warn his scientific *confrères* of its shortcomings. The results obtained, he says, have usually shown themselves to be too high, and he would therefore recommend its use only where high temperatures have to be resorted to, or where metals are attacked. "*Es sollte das Luftverdrängungsverfahren eben nur da angewendet werden, wo die anderen Methoden nicht oder nur schwer benutz werden können; also bei sehr hohen Temperaturen und bei Substanzen, die Metalle angreifen.*" As a matter of fact, the method completely fulfills its function—which is, in reality, to determine whether the molecular weight of a substance is its simplest formula weight (as determined by analysis) or a multiple of this.

It is but fair to add that the laws of osmotic pressure have since taught us methods of determining molecular weights, which, in turn, threaten to supplant Victor Meyer's method.

His vapor density method led to an almost endless series of pyrochemical studies which were continued without interruption to the day of his death. At first inorganic substances, the molecular weights of which were doubtful, were investigated. Here most of the work was done in collaboration with Carl Meyer (no relative).[21] Phosphorus pentasulphide, indium chloride, cuprous chloride, arsenious oxide, and ferric chloride among others were closely studied. Then came a study of elements in the gaseous state (at yellow heat): mercury, oxygen, and chlorine. The last gave rise to much heated discussion, for at one time it tended to reopen the long-buried controversy as to the elementary nature of chlorine.

Thiophene.

Victor Meyer's fascinating piece of research, the discovery of thiophene, does not fit into his scheme of well-ordered investigations. As has been stated, its discovery may be attributed to —what seemed at the time—a faulty lecture experiment. In the preface to his book on "Die Thiophengruppe"[48] he says: "How I happened to hit on it must be attributed to an accident. In one

* "These methods (Diemar, Bunsen, Gay-Lussac, A. W. Hofmann) . . . are seldom employed at present in laboratories, because the recently published method of V. Meyer, characterized by simplicity in execution, affords sufficiently accurate results for all ordinary purposes." (Richter,[44] vol. i., p. 27.)

of the demonstrations I wished to show my students the color reaction for benzol—which depends upon the fact that benzol, or, as one must now say, coal-tar benzol (containing thiophene), when mixed with isatin and sulphuric acid, gives the deep blue indophenin reaction. I repeated this reaction before the demonstration and all went well. To my surprise, when I performed the test for the students the result was negative." His attention was immediately drawn to the source of his benzene, and the information was unearthed that whereas the benzene used for the lecture experiment was obtained from benzoic acid by distillation with alkali, that tried previous to the demonstration was a sample from coal-tar. Repeating the test with a coal-tar benzene, no difficulty was experienced in obtaining a positive reaction. On the same day Meyer convinced himself that the purest form of benzol obtained from coal-tar gave the indophenol reaction, and that by long heating or continued shaking of the hydrocarbon with sulphuric acid the blue color grew more and more faint. The sulphonate formed with sulphuric acid was dry distilled, and the distillate gave an intense indophenol reaction.

In his first paper [22] Meyer advanced three hypotheses to explain this curious behavior: (1) Mixed with benzene from coal-tar there may be a small amount of impurity present which acts similarly to zinc dust and aluminum chloride; that is, like a catalytic agent, "activating" the otherwise indifferent benzene. (2) Again, it may be that in benzene from benzoic acid there is an accompanying impurity which inhibits the reaction.* (3) Possibly the benzol from coal-tar contains two compounds, much alike in chemical and physical properties, one of which is, however, more reactive. The more reactive one, to which the isatin reaction may be due, is the first to be transformed into a sulphonic acid.

The last assumption proved correct.[23] The commercial benzene from coal-tar was found to contain about 0.5 per cent. of a substance, boiling-point 84° C., which, in its properties, showed similarities to benzene, and to which the isatin reaction was due.

Meyer first convinced himself that none of the common impurities found with benzene had any effect on the reaction. For

* Meyer, however, points out that the ordinary impurities in benzene from benzoic acid (diphenyl, benzophenone, etc.) do not seem to influence the reaction.

this purpose he successively mixed an "inactive" benzene (that is, a sample that did not give the isatin test) with toluol, xylol, naphthalene, anthracene, pyridin, quinolin, anilin, etc., but not in a single case was the test obtained. Ethyl mercaptan showed itself an exception; here the blue color appeared, but disappeared within a few minutes.

Further, benzoic acid, prepared from a Merz sample of coal-tar benzol by sulphonation and distillation with potassium cyanide, when distilled with sodium hydroxide, yielded a benzol which gave a positive isatin reaction.

Meyer prepared the new substance from ten litres of benzol by the sulphonation method. From the sulphonic acid a few cubic centimetres of liquid, boiling at 85° C., which did not solidify on cooling with a mixture of ice and salt, and which contained appreciable quantities of *sulphur*, was obtained. This liquid gave an intense isatin reaction—so much so, that it had first to be diluted with "inactive" benzol or ligroin before the isatin and sulphuric acid could be added.

It was clear now that the reaction was due to some substance *in* the benzol.

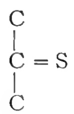
Now, argued Meyer, since this new substance contains sulphur, indophenin itself—the result of the reaction of isatin and sulphuric acid on coal-tar benzol—probably contains this element also. And indeed he showed that the purest samples of indophenin and bromindophenin, with which his friend Baeyer supplied him, contained sulphur.

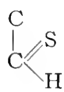
Through the kindness of R. Bindschendler the facilities of the dye factory of Bindschendler, Busch & Co. were placed at Meyer's disposal. He was thereby enabled to prepare the new compound in appreciable quantities. Two hundred and fifty litres of the purest commercial benzol were shaken for four hours with 25 litres of concentrated sulphuric acid. The resulting sulphonic acid, when converted into its lead salt, yielded 16 kilogrammes. This lead salt consisted mainly of the salt of the new sulphonic acid, mixed with a little lead benzene sulphonate. This was decomposed with hydrogen sulphide, filtered from lead sulphide, and the filtrate submitted to dry distillation. Later, adopting Caro's modification, the process was considerably improved by distilling the lead salt with one-quarter its weight of ammonium chloride. The raw distillate was purified by shaking first with water, and then with concentrated sodium hydroxide,

and finally freed from water with calcium chloride. This was again distilled. The oil so obtained, when further freed from water by means of calcium chloride, showed itself to be a mixture of about 70 per cent. of the new substance and about 30 per cent. benzol. For further purification, 20 c.c. samples of raw thiophene were diluted with 2 litres of ligroin and shaken with 200 c.c. concentrated sulphuric acid until the ligroin layer no longer gave an isatin reaction (this required from one to two hours). The thiophene sulphonate was separated from the ligroin, diluted with water, and lead carbonate added. The lead salt was next decomposed with hydrogen sulphide, filtered, and the filtrate, consisting of thiophene sulphonic acid, quite free from benzol derivatives, was dry distilled. The thiophene so obtained was washed with potassium hydroxide, dried by means of calcium chloride, and once again distilled. The liquid boiled at 84° C., and analysis and vapor density determinations showed it to have the formula C_4H_4S.

The following year Victor Meyer considerably improved the method of preparation.[24] He found that by the use of a limited quantity of sulphuric acid the thiophene could be extracted direct from coal-tar benzene without the accompaniment of any benzol. Two thousand kilogrammes of pure coal-tar benzol were shaken with 100 kilogrammes of concentrated sulphuric acid for six hours. The resulting sulphonic acid was converted into the corresponding lead salt, and this distilled with ammonium chloride, yielding chemically pure thiophene. For every kilogramme of the lead salt 135 grammes of thiophene were obtained. The sulphur calculated for $C_4H_4S = 38.1$ per cent.; as actually found = 37.9 per cent.

With regard to the constitution of the new compound, Meyer, in this early paper of his, advanced three possibilities as to the part played by the sulphur in the configuration of the molecule:

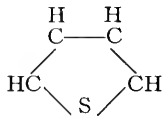

(1)


(2)


(3)

The first, a thioacetone, would have had a tendency to coalesce into two molecules; the second, a thioaldehyde, was immediately dismissed by Meyer as not in any way agreeing with the known properties of the substance; the third seemed most

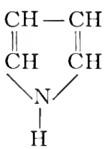
probable. In that case the configuration, thought Meyer, might be of some such nature as this:



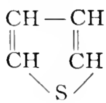
And this later investigation fully confirmed.[25] The name finally adopted for the new compound was "thiophen"—"thio" because of its sulphur content, and "phen" as showing its similarity to the phenyl group. Well was Meyer justified in writing that "*ihre (der Thiophen) grosse Aenlichkeit mit der correspondierenden Derivaten des Benzols . . . scheint sich ein weites Gebiet zu öffnen, dessen Bearbeitung eine Ausbeute an interresanten Körpern in Aussicht stellt: an Körpern, deren Eigenschaften denen der analogen Abkömmlinge des Benzols gleichen, und auch eine ähnliche Constitution besitzten, nur das sie, statt von Benzol, von einem schwefelhaltigem Stammkorper mit 4 Atomen Kohlenstoff deriviren.*"[23]

The similarity between thiophene and benzol was strikingly shown by the preparation of the homologues of thiophene * and its derivatives, such as tetrabrom thiophene, C_4Br_4S; thiophen-sulphonic acid, $C_4H_3S-SO_3H$; thiophensulphochloride, $C_4H_3S-SO_2-Cl$; thiophensulphamide, $C_4H_3S-SO_2-NH_2$; thiophennitril, C_4H_3S-CN; thiophencarboxylic acid, $C_4H_3S-COOH$;[26] nitro-compounds;[27] condensation products by the use of Baeyer's and Friedel-Craft's reactions,[28] etc.

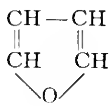
Further, Meyer showed that pyrrol, like thiophene, reacts with isatin and sulphuric acid, and the latter is the mother substance of an almost innumerable series of dyes closely related to those obtained from pyrrol. This, and the evidently close relationship between furfurane and thiophene



Pyrrol



Thiophene



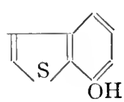
Furfurane

* The methods used for preparing the homologues of thiophene are in every way analogous to those used in the preparation of the corresponding benzol homologues.

seemed to justify the conclusion that of the three acetylene groups in benzene, *one* can be replaced either by S, O, or NH, without materially altering the character of the benzene ("*ohne dass dadurch der eigenthümliche Charakter des Benzols und seiner Abkömmlinge aufgehoben wird*" [29]).

Methods of producing thiophene otherwise than from benzene were developed by Meyer. Thus he found that it could be obtained—in small quantities, to be sure—by passing acetylene or ethylene over boiling sulphur; [30] by passing ethyl sulphide through tubes heated to redness; by bringing ethylene or illuminating gas over heated pyrite; by heating crotonic, butyric (*not* isobutyric), or valerianic acid, or paraldehyde with phosphorus trisulphide.[31]

What held true for benzol Meyer found to be true for toluol, xylol, etc. Thus he found that Laubenheimer's reaction for anthraquinone—where toluol, drop by drop, is added to a dilute aqueous solution of anthraquinone, then, under cooling, sulphuric acid, and, after a few minutes, some water is added; the mixture, when treated with ether, gives a beautiful violet-red—is not given if the toluol used be *pure*. By merely shaking the toluol for some time with concentrated sulphuric acid Laubenheimer's test proved negative. Further, coal-tar toluol was shown to contain sulphur, whereas toluol, first treated with sulphuric acid, did not. This led Meyer to conclude that in coal-tar, side by side with the benzene hydrocarbons, there are a whole series of corresponding thiophene derivatives,[32] which, indeed, was shown to be the case. [29, 33, 34] Toluol (methyl benzol), for example, was found to contain thiotolene (methyl thiophene)—(see also Richter,[44] 2, 453). And the many possibilities of extending the whole subject were still further revealed when by the use of Fittig's condensation a thiophene of the naphthalene series was obtained: thiophene-aldehyde and succinic acid were condensed, giving the α-naphthol of the thiophene series:[35]



Like all his other researches, his thiophene work reveals the man with the true scientific trend—the method of logically developing a subject. The first slow method of extracting thiophene from coal-tar was followed by improved methods; then came the recog-

nition of its close constitutional similarity to benzol, and further to furfurane and pyrrol; and from here on to an endless series of homologues, substitution products, isomers—with their properties closely allied to the corresponding benzene derivatives.

. . . .

This is far from an exhaustive account of Meyer's activities. Little more than the *leit-motivs* in his researches could be touched on. And much of his work—especially that pursued during his last years in Heidelberg—has not been touched on at all; for example, his studies concerning the slow combustion of gas mixtures,[36] the dissociation of hydrogen iodide,[37] the iodo, iodoso, and iodonium compounds —where iodine functions as does nitrogen in ammonium substances,[38] steric hindrance * [39]—to mention but a few.

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* "*Sobald in einer substituierten Benzoesäure die beiden, den Carboxyl benachbarten Wasserstoffatome durch Radikale, wie Br, NO_2, NH_2, CH_3, unsw. ersetzt sind, resultiert eine Säure, welche durch alcohol und Salzsäure nicht, oder nur sehr unvollständig verestert wird.*"

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Electrolytic Chlorine for Laundries. H. P. HILL. (*Electrical World,* vol. 68, No. 5, July 29, 1916.)—For several years a number of the larger laundries have prepared their own bleaching material by the electrolysis of salt solution, finding it cheaper to produce their own "bleach" than to purchase the bleaching compounds which are largely manufactured abroad and exported to this country. In recent months, however, the sharp advance in prices of bleaching compounds of all kinds has made it increasingly desirable for even smaller laundries to produce their own chlorine solution by the electrolysis of salt and water. The electrolytic load thus afforded the central station is comparatively long-hour in character, and may be arranged so as to fall entirely during the daylight hours.

A 50-gallon outfit requires 25 ampères of direct current at 110 volts. The equipment comprises a 50-gallon wood tub mounted on a stand three feet above the floor and filled with a solution of common salt and water. The tub is provided with a revolving paddle to agitate and dissolve the salt. Alongside of the tub is mounted a soapstone box containing the electrodes. The salt water from the tub is admitted to the negative element and is discharged at the positive element. From the discharge the chlorine solution flows into a tub on the floor, from which it is dipped and used in the washing machine.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE INTERNATIONAL SYSTEM OF ELECTRIC AND MAGNETIC UNITS.†

By J. H. Dellinger.

Two electric units, the international ohm and ampère, have been defined in terms of definite standards by international congresses. These standards are maintained by the national standardizing laboratories, and are the basis of all electrical measurements. The units of the various electric and magnetic quantities are derived in practice from these fundamental units by the ordinary equations of electrical theory. Thus a complete and distinct system of electric and magnetic units is in use, based on the international ohm and ampère, the centimetre, and the second. While these international units differ in their derivation from the electrostatic and electromagnetic units, they nevertheless represent very closely the theoretical electromagnetic units. The very slight differences in magnitude between the international and the corresponding electromagnetic units are determined by absolute measurements made from time to time. The electromagnetic units are of much less practical interest than the international units.

One of the reasons why the international system is the most convenient and the most used electrical system is because it is centred around the phenomena of electric current. Electric current is more familiar and of vastly greater practical importance than electrostatic charges or magnetic poles, upon which the other two familiar systems are based. In the international system the magnetic pole is given a subordinate position. Since a free magnetic pole does not exist in Nature and magnetic pole strength does not appear in engineering formulæ, its prominence in the electromagnetic system has not been an advantage of that system. Another fortunate aspect of the international system is the con-

* Communicated by the Director.

† Scientific Paper No. 292.

venience of its dimensional expressions. They are very simple, and directly suggest the ordinary relations of electrical theory and practice. They are, in fact, as helpful in electricity as the usual dimensional expressions in length, mass, and time are in the domain of mechanics. The international electrical system is valuable only in electricity and magnetism, having no utility in mechanics or other parts of physics. It gives dimensions as awkward for the quantities of mechanics as the electromagnetic system gives for electrical quantities, and is, therefore, not of such general application as the systems in which length, mass, and time are fundamental.

The international system furnishes no justification for the use of the word "gauss" as the name for both the unit of induction and the unit of magnetizing force. This double usage is an inconvenience in practice.

New systems of electric and magnetic units have been proposed from time to time, and some of these are now used to a limited extent in certain books and publications. They all involve the definition of new units of certain quantities in such a way as to redistribute the factor 4π in the equations. An attempt to redistribute the 4π's in an advantageous manner has been called "rationalization" in the literature of the subject. A careful study has been made to determine whether the advantages of these proposed systems are such as to justify the trouble and confusion incident to a general change of units. No such advantage has been found. Of course, no system eliminates the 4π entirely. All of the proposals except Heaviside's involve changing the unit of permeability by a multiple of 4π. While Heaviside's system leaves permeability unchanged, it makes a drastic change in practically every other unit.

A strong reason against a general change of units for the purpose of rationalization is the fact that a rationalized system is obtained merely by using the ampère-turn as the unit of magneto-motive force. Upon writing the equations necessary to make this widely used unit fit in with the other units, the system is found to be as good as, or actually superior to, the various proposed systems in every respect. It is interesting that the units which have undergone the evolution of actual use are not wanting in academic appropriateness.

THE DENSITY AND THERMAL EXPANSION OF AMERICAN PETROLEUM OILS.*

By H. W. Bearce and E. L. Peffer.

[ABSTRACT]

This paper gives an account of the experimental works on which are based the expansion tables of Circular No. 57, "United States Standard Tables for Petroleum Oils." It gives a detailed description of the methods and apparatus employed in the determination of the density and thermal expansion of petroleum oils from the various oil fields of the United States.

The paper will be of interest to oil producers and refiners throughout the country.

A VARIABLE SELF AND MUTUAL INDUCTOR.†

By H. B. Brooks and F. C. Weaver.

[ABSTRACT]

This paper outlines the development of a new form of instrument for varying the self-inductance of a circuit, or the mutual inductance between two circuits. It consists of two pairs of fixed coils held in stationary hard-rubber disks, between which a third disk carrying two coils is arranged to be rotated. The form and the spacing of the coils were determined so as to secure the following advantages: (1) high ratio of inductance to resistance; (2) scale divisions of uniform length reading directly in units of inductance; (3) astatic arrangement of the coils, which reduces the liability of errors caused by the proximity of other instruments or of conductors carrying currents. Diagrams and data are given from which instruments of this type can be designed for given uses. Comparison is made of the new instrument and of some other older forms of variable inductor, including the Ayrton-Perry.

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* Technologic Paper No. 77.

† Scientific Paper No. 290.

PROPERTIES OF THE CALCIUM SILICATES AND CALCIUM ALUMINATES OCCURRING IN PORTLAND CEMENT.*

By P. H. Bates and A. A. Klein.

[Abstract]

With the settlement of the question of what are the constituents of Portland cement, the next important one is, What part does each of these play in developing the physical properties of the cement? The present investigation was undertaken to study these phases of the subject.

One of the first difficulties encountered was that of producing the three constituents present in Portland cement of normal composition and burning (tricalcium silicate, $3CaO.SiO_2$, dicalcium silicate, $2CaO.SiO_2$, and tricalcium aluminate, $3CaO.Al_2O_3$) in sufficient amounts to allow of determining the rate of setting the rate of hydrating, both chemically and microscopically, and the rate of gaining strength, both as a neat and 1 : 3 standard sand mortar test-piece. A preliminary investigation of a number of commonly used "mineralizers" ("mineral catalyzers") showed that either in the presence of small amounts of boracic acid or chromium oxide both of the silicates could be produced, although to produce the tricalcium silicates six successive burnings were required. As the aluminate is not stable at its melting-point, it was made by heating it for some time below this point, and was secured without the use of any "mineralizer."

Some burnings were also made of raw materials of the composition of the silicates, to which about one per cent. alumina was added. Products resulted which it was thought would be of considerable value when determining the effects of alumina upon the properties of the silicates. Also, some burnings were made to which alumina had been added to the raw mixes in such amounts that in one burn approximately 19 parts of tricalcium aluminate would be present in the burned material with 81 parts tricalcium silicate; in another the same amount of aluminate would be present with 81 parts of dicalcium silicate, and in a third the same amount of aluminate would be present with 81 parts of equal amounts of each silicate. It was not expected that the silica would combine

* Technologic Paper No. 78.

in either burn according to the calculations, but that there would tend to be more of the tricalcium silicate in the low silica mix and more of the dicalcium silicate in the low lime mix. It was also thought that valuable results would be obtained from these burns when compared with mixes of a similar composition formed by grinding together the compounds burned separately.

The physical tests usually carried out with Portland cement were made with each of the burns, and also with cements prepared as follows: By grinding together each silicate (using separately the one prepared with the boracic acid and the one prepared with chromium oxide) with three per cent. of plaster; also, 81 parts of each silicate with 19 parts of aluminate, and, also, adding three per cent. plaster to this mixture; also, adding three per cent. plaster to a mixture of equal parts of the two silicates; also, grinding together 81 parts of a mixture of equal parts of each silicate with 19 parts of aluminate, and by adding three per cent. plaster to this. In addition to the usual tests, the amount of hydration was determined in one neat test-piece at each period broken by determining the percentage of water of hydration; microscopical examinations were also made of these test-pieces to determine the degree and character of hydration.

The results show that the aluminate sets and hydrates so very rapidly that it is almost impossible to make test-pieces. This is accompanied by a great evolution of heat. It never attains a tensile strength much beyond 100 pounds per square inch. When mixed with the silicate it affects the latter more markedly in the time of set than in the strength, tending to hasten the former and slightly reduce the latter.

The dicalcium silicate sets so slowly that the obtaining of test-pieces is difficult, on account of breaking them at the early periods by handling. At the end of one year it has a tensile strength of about 600 pounds per square inch and 5.5 per cent. water of hydration. At seven days test-pieces made of it have to be handled with extreme care and are easily crumbled in the hand; at fourteen days test-pieces broke at about 60 pounds per square inch. Mixed with three per cent. plaster, it acquires a little more strength; mixed with 19 parts aluminate, its strength is also improved somewhat. Mixed with equal parts tricalcium silicate, it reduces the early strength of the latter, but at late periods gives a very desirable cement.

The tricalcium silicate has all the properties of Portland cement; especially does it resemble the latter in the matter of set and strength. The addition of aluminate to it has a tendency to reduce the early strengths; plaster and aluminate increase the early strengths, but reduce the later ones. The mixture with dicalcium silicate, with or without plaster, gives low early strengths but increases consistently with age. The addition of aluminate, and aluminate with plaster, to the mixture of the two silicates increases the strength of the mixture at the early periods, but is not advantageous for later strengths.

A comparison of cements produced by grinding together the compounds, with those of similar composition made by burning, shows a marked similarity between the two and would almost lead to the conclusion that it would be possible to reproduce any cement, knowing the amount of each constituent, by grinding together the constituents after their separate burning.

The function of alumina in finished cement is a matter of some question. Cements can be produced satisfactorily, both in respect to time of set and strength, when it is present in amounts less than one per cent. Such cements can be manufactured only at high temperatures and with longer time of heating than is now used. It is therefore a necessity from the manufacturing standpoint, acting as a flux and reducing both the time and degree of burning.

The character of the hydration of the two silicates is such that a preponderance of either in a cement would seem to be undesirable. The dicalcium silicate, even at the end of a year's hydration, shows a very granular, sandy, porous mass; the tricalcium silicate at the end of a week is very dense, with a semi-vitreous lustre. The porous formation of the former affords too ready egress of solutions which may crystallize out and cause disintegration, or cause loss of strength through chemical reaction of the silicate with solutions; the dense structure of the latter, being due largely to the gelatinous or colloidal products of the hydration, is poorly adapted to withstand moisture or temperature changes, to the former of which colloids are extremely susceptible.

The actual products of the hydration of the two silicates and the aluminate are, with one exception, as noted by Klein and Phillips,* as follows: In the case of the aluminate, the immediate

* "Hydration of Portland Cement," Klein and Phillips, Tech. Paper No. 43, Bureau of Standards.

hydration is the formation of a gelatinous form of hydrated tricalcium aluminate ($3CaO.Al_2O_3 + H_2O$); this changes, in the course of time, to a crystalline form of the same compound; the water of hydration is loosely combined, part being lost in dry air. In the same case of the tricalcium silicate, the hydration results in the formation of a colloidal hydrated silicate and hydrated lime which is largely crystalline, though the crystals are usually poorly formed and are well scattered through the dense mass of colloidal silicate. In the case of the dicalcium silicate, the hydration results in the formation of a colloidal hydrated silicate and crystalline lime hydrate; this latter is very well crystallized and, on account of the porous nature of the hydrated silicate, occurs in large crystals. The presence of these hydrate crystals was not noted by Klein and Phillips, and they occur only when the cement is gauged with small amounts of water.

A SYSTEM OF REMOTE CONTROL FOR AN ELECTRIC TESTING LABORATORY.*

By P. G. Agnew, W. H. Stannard, and J. L. Fearing.

[ABSTRACT]

THE system was developed primarily for use in testing electrical measuring instruments. Small multiple lever controllers may be operated in any one of several laboratory rooms to give complete control of the output of a group of motor-generator sets. For example, in testing a wattmeter, or an alternating-current watthour meter on low power factor, the five levers of a controller give both a coarse and a fine adjustment of frequency, current, voltage, power factor, and an auxiliary direct-current voltage, respectively.

The field rheostats are very long, slide-wire resistances. They are tubular in form, and are wound helically with the resistance wire. They are 32 mm. in outside diameter, and as much as 12 metres in length. When necessary, they are cooled by circulating water through the tube. Special laminated brushes which bear directly on the winding are operated by small, worm-geared

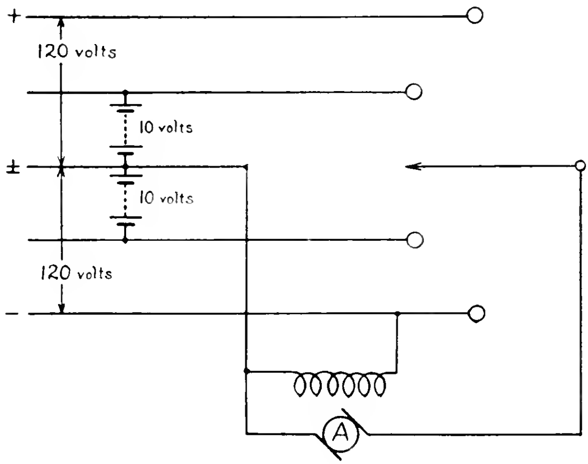
* Scientific Paper No. 291.

motors which pull them along the tubes by means of cord and pulley.

The coarse adjustment is obtained by operating the motors at normal speed, while for the fine adjustment the armatures are connected to a low-voltage battery, giving a very much lower speed. Fig. 1 shows how the 2-direction, 2-speed control is obtained with a single contact lever, by the use of a modified 5-wire system of power distribution for the operation of the motors.

Settings can be made to 0.02 per cent. in nearly every case.

FIG. 1.



Two methods of phase control are used. In one, two similar generators are on the same shaft, and the stator armature of one generator is shifted by a motor-operated worm drive. In the other method a worm drive operates the rotor of a phase-shifting transformer.

A large, motor-operated, low-voltage rheostat for currents up to 10,000 or 12,000 ampères is included in the system. Laminated brushes bear directly on water-cooled resistance tubes.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

PHOTOMETRIC METHODS IN CONNECTION WITH MAGIC-LANTERN AND MOVING-PICTURE OUTFITS AND A SIMPLE METHOD OF STUDYING THE INTRINSIC BRILLIANCY OF PROJECTION SOURCES.†

By J. A. Orange.

THIS article gives the practical details of the apparatus required and manipulation for the purposes indicated in the title.

THE HIGH-FREQUENCY SPECTRUM OF TUNGSTEN.

By Albert W. Hull and Marion Rice.‡

THE spectrum of tungsten at voltages up to 150,000 has been studied and photographs are given showing the first, second, and third order reflections of the $K\alpha$ and $K\beta$ lines. The position of the K lines in relation to the general radiation at various voltages has been studied by means of the ionization chamber and is shown on curves of intensity for seven voltages between 40,000 and 103,000. The lines first appear at 80,000 volts, increasing in intensity with rising voltage. Kossel's quantum relations between the frequencies of K and L lines hold true for the tungsten lines. All the lines, including tungsten, can be expressed by the empirical formulæ:

$$\gamma\alpha = 1.64 \times 10^{15}\ N^{2.10} \text{ for the } \alpha \text{ lines,}$$
$$\gamma\beta = 1.56 \times 10^{15}\ N^{2.15} \text{ for the } \beta \text{ lines,}$$

where γ is the frequency and N the atomic number.

The shortest wave-length observed was 0.08 A. U. The proportionality between frequency and voltage observed by Duane and Hunt holds accurately up to 100,000 volts and less accurate measurements indicate its constancy up to 150,000 volts.

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* Communicated by the Director.

† *General Electric Review*, **19** 404–5, May, 1916.

‡ *Proc. Nat'l Academy of Sciences*, **2** 265–70, May 15, 1916.

THE DISSOCIATION OF HYDROGEN INTO ATOMS. III.—THE MECHANISM OF THE REACTION.

By Irving Langmuir.*

A NEW theory of heterogeneous reactions avoiding certain assumptions of the earlier one, which experiment has recently proved untenable, is advanced. The earlier hypothesis considered that the surface of a tungsten wire in contact with hydrogen contained atoms and molecules of the gas in chemical equilibrium with each other, the two forms escaping at rates respectively proportional to their concentrations in the wire, and being absorbed at rates proportional to the corresponding pressures in the gaseous phase. The equation for heat loss from the wire thereby deduced agreed extremely well with experimental results over a range from 0.01 to 760 mm. pressure and 1000 to 3500° K. temperature. But the velocity of the reaction by which hydrogen in contact with a hot tungsten wire is dissociated is so enormous as to preclude the possibility of the existence of the gas as a solid solution in the metal with the attendant necessarily low rate of diffusion. Moreover, experiment has shown that, while 68 per cent. of all hydrogen molecules striking the filament at high temperatures reach chemical equilibrium before leaving it, at lower temperatures, up to 1500° K., only 19 per cent. reach thermal equilibrium, a fact for which the earlier theory offers no explanation. Work in gases at low pressures has demonstrated that electron emission is dependent upon the composition of the surface layer of atoms, and that reaction between gas and solid is also dependent upon the composition or structure of the same. It has become necessary, therefore, to assume that reaction occurs directly on the surface of the metal and involves no diffusion through even a single layer of atoms.

The new theory involves the view that on the surface of the metal the forces which hold its atoms together tend to be chemically unsaturated, and atoms or molecules of gases may be firmly held by them. In general accordance with the law of multiple combining proportions, each metal atom of the surface will be capable of holding a definite integral number of atoms of gas, or perhaps two metal atoms may hold one gas atom. Atoms or molecules so held are a part of the solid body, a real continuation of the space

* *Journal of the American Chemical Society*, **38**, 1145–56, June, 1916.

lattice of the solid, and may be said to be adsorbed. The surface of the metal is thus looked upon as a sort of checkerboard of a definite number per square centimetre of elementary spaces, each capable of holding an atom or a definite part of a molecule of adsorbed gas.

Application of this theory to the dissociation of hydrogen leads to equations identical with that derived by the older theory, which had previously (Parts I and II) been shown to be in complete accord with experimental results.

All the hypotheses considered lead to the conclusion that only a small fraction of the surface is covered with hydrogen, and that phenomena within the metal do not affect the reaction. This conclusion is confirmed by the difference in the accommodation coefficient of hydrogen in contact with tungsten at low and high temperatures, which is now easily explained by supposing the surface of the metal to be largely covered by adsorbed hydrogen at the lower temperatures and practically bare at the higher temperatures. The 19 per cent. may then correspond to the fraction of molecules condensing when they strike a surface already covered and 68 per cent. when they strike a bare surface. That the surface of tungsten is practically bare at the higher temperatures is strongly influenced by the fact that the electron emission is not perceptibly influenced by the presence of pure hydrogen.

A HIGH VACUUM MERCURY VAPOR PUMP OF EXTREME SPEED.

By Irving Langmuir.*

A NEW high vacuum mercury vapor pump, called the diffusion pump, has been devised, and its operation is explained and illustrated by a diagram. It has the advantages of extremely high speed of exhaustion, constant at all pressures, and absence of lower limit to which pressure may be reduced. The maximum speeds of exhaustion so far obtained have been 4000 c.c. per second for air and 7000 c.c. per second for hydrogen at pressures below 10 bars. Theoretical considerations indicate that this speed should remain constant down to the very lowest pressures. Further advantages are reliability and simplicity, in which respects the pump has been much improved by modifications in form and material, which will be described in later papers.

* *Physical Review*, **8**, 48–51, July 19, 1916.

Lamp-filament Breaker. ANON. (*Electrical World*, vol. 68, No. 5, July 29, 1916).—A device for breaking the filaments of incandescent lamps which are turned into its supply department has been constructed by the Boston Edison Company, and is in regular use in the local lamp division. Among the thousands of incandescent lamps returned as having been burned out by customers are many which, though not entirely useless, are nevertheless unfit for further service. To prevent purchasers from sorting the units and reselling these with filaments intact, a means of breaking the filaments of lamps of sizes up to 250-watt tungsten was sought. As a result, an apparatus was constructed consisting of a laminated U-shaped electromagnet with a gap sufficiently wide to admit a large-sized unit between its jaws. The winding, in series with the resistance, is supplied from a 110-volt direct-current circuit. A powerful electromagnet is thus formed, whose field is produced by 7600 ampère-turns. A quick-acting lamp socket is arranged between the jaws of the U and is supplied, in series with a resistance, from a 220-volt alternating-current circuit. In addition to this fixed resistance, another can be switched-in in multiple.

As a lamp is pushed into the socket the effect is to break the filament instantly. The resistance in series with the lamp prevents short-circuiting on the 220-volt main in case of an occasional defective base. If, as sometimes happens with very large tungstens, the filament breaks and welds near the leading-in wires, the second resistance is thrown in with the lamp, thus allowing more current to flow and invariably breaking the filament. The direct-current field is left on continuously while operating. With this apparatus filaments are broken as rapidly as the lamps are inserted in the socket and placed to one side, and the lamp is in no way injured, nor is the blackening of the bulb increased.

Air Blast Alternating-current Rectifier. ANON. (*Electrical World*, vol. 68, No. 3, July 15, 1916.)—A very simple and ingenious method of rectifying high-tension alternating currents by means of an air blast has been assigned to the International Precipitation Company of Los Angeles, Calif., under United States patent 1,188,597. Wolcalt and Rieber propose to surround a rod electrode, spaced from a coöperating disk electrode, with an air blast at a pressure of about 10 pounds to the square inch. By directing the air blast along the path of the discharge, the inventors maintain that an alternating current of as much as 50,000 volts can be wholly rectified. It is also found, the inventors state, that by regulating the air-pressure it is possible to secure any desired amount of rectification. It also becomes possible to rectify both halves of an alternating-current wave and obviate entirely all expensive equipment of vacuum tubes etc.

NOTES FROM NELA RESEARCH LABORATORY.*

THE TUNGSTEN ARC UNDER PRESSURE.

By George P. Luckey.

THE following experiment was undertaken primarily for the purpose of determining whether the temperature of melting tungsten showed a marked change under pressure. For this purpose a tungsten arc was used, and the melting-point of tungsten in an atmosphere of nitrogen was determined for pressures up to 35 atmospheres. The red black-body temperatures of the melting tungsten for $\lambda = 0.661\ \mu$ were measured by means of a Holborn-Kurlbaum pyrometer of the type in general use in this laboratory. The values used for the absorption coefficient of tungsten in computing the true temperature were obtained by extrapolating from values obtained by Worthing for temperatures up to 3200° K.

The results of the melting-point determinations are given in Table I. The melting-point apparently decreases as the pressure is increased, but it is open to doubt whether this observed change is due to an actual decrease in the temperature of the tungsten, or whether the apparent diminution in brightness might not be due to an increased absorption of the gases above the surface of the tungsten. Above 12 atmospheres rather large uncertainties in the determination of the melting-point were introduced by the distortion of the image due to the refraction of the heated gases in the neighborhood of the arc.

The value of the melting-point found for atmospheric pressure agrees closely with that found by Worthing in the tungsten arc, 3630° K., while it is about eighty degrees higher than the value determined by Langmuir, 3540° K. This discrepancy is due to the different value of the emissivity of tungsten taken in the two cases. The value used by Langmuir was 0.425 at 0.667 μ, and that found from the extrapolation of the values obtained by Worthing was 0.393 at 0.661 μ. The red black-body temperatures obtained give good agreement in all cases. The value found

* Communicated by the Director.

by Langmuir was 3124° K. for 0.667 μ, while that found by Worthing was 3140° K. for 0.666 μ.

At the point where the main arc discharge centres on the electrodes of the arc, a temperature much higher than that of the surrounding melted tungsten was noticed. The temperature of this area varied with the pressure, the current through the arc, and the area over which the discharge took place. Measurements of the highest attainable red black-body temperature for 0.661 μ were made of this area at different pressures, and the values found are given in Table II. If it be assumed that the relationship found by Worthing between the absorption coefficient and the temperature of tungsten holds up to the temperatures here attained, then the values of the true temperature would be given in the last column of Table II. There is a question as to what this temperature represents. It is doubtful whether it can be assumed to be the boiling-point of tungsten. It is more probable that it represents some temperature lying between the melting- and boiling-points.

In connection with the temperature determinations, measurements were also made of the electrical characteristics of the tungsten arc in nitrogen under pressures from one to thirty atmospheres. The drop in potential across the arc, other conditions being the same, increased with the pressure, an effect similar to that observed by Duncan Rowland and Todd on the carbon arc under pressures up to ten atmospheres. At high pressures the voltage dropped as the current was increased until values of current of about five ampères were reached, after which the voltage rose with increasing current. This latter effect was probably due to the tendency of the arc to flare out to one side with larger currents, as well as to the increase of pressure in the tank caused by the heating of the gas.

TABLE I.

Apparent Melting-point of Tungsten Under Pressure.

Pressure, atmospheres	Red black-body temperature, $\lambda = 0.661\mu$	True temperature
1	3138° K.	3623° K.
4	3129° K.	3611° K.
8	3116° K.	3594° K.
11	3113° K.	3590° K.
14	3107° K.	3582° K.
18	3099° K.	3572° K.
21	3092° K.	3562° K.
28	3093° K.	3564° K.

TABLE II.

Highest Attainable Temperatures.

Pressure, atmospheres	Red black-body temperature, $\lambda = 0.661\mu$	Assumed absorption coefficient	Computed true temperature
1	3559° K.	0.374	4235° K.
8	3794° K.	0.363	4602° K.
15	3907° K.	0.358	4782° K.
22	3982° K.	0.354	4912° K.
29	4022° K.	0.352	4978° K.
33	4086° K.	0.349	5084° K.

Nela Research Laboratory,
National Lamp Works of General Electric Company,
Nela Park, Cleveland, Ohio.

Armor-plate. ANON. (*The Times* (London) *Engineering Supplement,* No. 500, June 30, 1916.)—The idea of using armor-plate as a protection against gun fire arose long before it was actually put into practice. It bore at first two aspects, the protection of shore batteries on the one hand, and of floating batteries on the other. The first was proposed and tested by Major-General Ford at Woolwich in 1827. A granite wall 7 feet thick was faced with two layers of iron bars 1¼ inches square, disposed vertically and horizontally; this defence was destroyed by shots from a 24-pounder gun. In America, Messrs. Stevens, of Hoboken, made some tests with 4-inch wrought-iron plates. In England, experiments were carried on in the dock-yards from 1846 to 1856, and in one series a 4½-inch wrought-iron plate was supported by a timber backing. In France, floating batteries propelled by steam were built for service in the Baltic during the Crimean War. The plates used were 4½ inches thick, 3 feet long, and 20 inches wide, and they were able to resist the Russian 32-pounders. Then came (1855) the first Armstrong breech-loading gun, which heralded a new era in artillery and the beginning of the intense struggle between the penetrative power of guns and the resistance of armor.

The first armored ship, as distinct from floating batteries, was the French *Gloire* (1855), having iron armor-plates 4¾inches thick. The plates were rolled at Creusot by Messrs. Schneider, who in due course (1876) also made the first steel armor-plates. At the same time that the *Gloire* was being completed in France, the famous *Warrior* was being built at Blackwall with iron-armor-plates 4½ inches thick. When the Palliser chilled point projectiles were introduced (1863), wrought-iron armor developed in the only direction it could take—an increase in the thickness of the plates, which in successive stages advanced from 4½ inches in the *Warrior* (1860) to 24 inches in the *Inflexible* (1880). The *Repulse* was provided with 6-inch armor in 1870, and the *Thunderer* with 12-inch in 1877.

When the *Inflexible* armor of 24 inches was fitted, it was necessarily made up of two thicknesses.

The beginning of the substitution of steel armor-plate for that of wrought iron dates from about 1878. In 1877, tests had been made by Whitworth and Cammell. Generally, the steel plates arrested the projectiles but suffered badly, being more or less cracked and shattered. The suggestion was, in consequence, put forward that the best solution might be found in a hard steel facing backed up by wrought iron, which would hold the fractured parts together. A plate with a hard steel face welded to a soft iron back, developed independently by Messrs. John Brown and Messrs. Cammell, embodied this idea. It was used in the British Navy for several years, and was, in fact, unrivalled until the advent of the solid steel plates produced at Creusot by the Schneider firm, who were the first to employ nickel to increase the tenacity of the steel. The modern Harvey, Schneider, and Krupp plates evolved since 1891 are developments in imparting to highly resisting solid steel plate a surface of intense hardness by cementation and subsequent quenching.

A Semi-floating Highway Bridge. ANON. (*Engineering Record*, vol. 74, No. 6, August 5, 1916.)—During the construction of a bridge across Costiac Creek, in Los Angeles County, California, highway traffic has had to ford the stream at a point where the depth is usually sufficient to submerge the carburetor of the average car. Teams have therefore been maintained at the crossing by the county to tow automobiles across. This procedure, however, usually caused considerable trouble in getting the engine started again, and it was recently determined to try a better method.

The stream has a sandy bottom, and the depth is fairly uniform, so it was decided to build a plank road in sections, and hold it in place by cables in such a way that a good surface would be continuous across the ford. By this plan the effective depth of the water would be decreased, not only by the thickness of the plank and stringers, but also by the amount which tires would otherwise sink into the soft, sandy bottom. As a matter of fact, the heavy plank units are so buoyant that light cars pass over them at fairly high speeds with practically dry tires, and, even at slow speeds, heavy cars can safely cross under their own power. After being built on shore and floated to place, the sections were held together by a 3/4-inch cable, threaded through eyebolts in each section. This cable was attached at 12-foot intervals, by means of 1/2-inch cables, to a 7/8-inch cable stretched across, 25 feet above the plank sections, and drawn sufficiently taut to hold it 4 feet above high water. On the down-stream sides the sections were wired together by strands of No. 12 galvanized wire. At each end of the ford 4-foot sections were left with free ends resting on shore. The total length of the crossing is about 104 feet. The bridge was completed in two days, at a cost of $17.50 for labor and $126 for material and transportation.

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Greatest World Petroleum Output. ANON. (*U. S. Geological Survey Press Bulletin,* No. 284, August, 1916.)—That 1915 was the most successful year of production in the history of the petroleum industry is shown by statistics just compiled under the supervision of J. D. Northrop, of the U. S. Geological Survey, Department of the Interior.

The total quantity of crude petroleum entering the world's markets in 1915, which amounted to 426,892,673 barrels, exceeds the former record, established in 1914, by 28,194,307 barrels, or 7 per cent.

The bulk of the increase in 1915 came from the United States and Mexico, though Russia, Argentina, and Japan recorded significant gains.

CURRENT TOPICS.

Contact Resistance of Metal Electrodes. N. K. CHANEY. (*Proceedings of the American Electrochemical Society*, April 27–29, 1916.)—In some unpublished work the writer has shown that under certain conditions a high "contact resistance" exists between the surface of an electrode of sheet zinc and the electrolyte. The "contact resistance" between zinc and ammonium chloride is a secondary development, occurring with measurable rapidity after the immersion of the zinc in the electrolyte. At the instant of immersion it is very small. It may rise to values of 200 to 400 ohms per square inch (1250 to 2500 per square centimetre) of electrode surface. It forms the principal part of the internal resistance of dry cells at low-current drains, and, as determined by measurements upon the latter, it has a high temperature coefficient, decreasing to one-tenth of its value with a temperature rise from 0° to 45° C. This is the contact resistance of the zinc electrode which was measured by Carhardt in his resistance measurements upon the early Gassner dry cells which caused the rapid rise in his resistance curves at low-current densities. With densities above certain low limiting values, it is lessened or temporarily destroyed, being practically unaffected by currents of less than 1 milliampère per 50 square inches (315 sq. cm.) of electrode surface, even if continued for a considerable time. At higher current densities it begins to rapidly decrease, and becomes negligible at current densities of about 1 ampère per 50 square inches. Upon open circuit the resistance again slowly rises toward its initial value. It is destroyed or very greatly reduced by chemical treatment of the zinc surface; *e.g.*, by corrosion with dilute sulphuric acid.

An explanation of these phenomena is based upon the supposed existence of a hydrogen film upon the electrode surface, discharged there by the local action between the zinc and the electrolyte. This is supported by a considerable amount of experimental evidence in which it is shown that the predicted behavior of such a hydrogen film under selected conditions is in agreement with the observed behavior of the contact resistance. These facts must have a significant relation to the theories of over-voltage phenomena and kindred problems bearing on the nature of the equilibria between the electrode surfaces and the electrolyte.

Electrolytic Coating of Silvered Mirrors. ANON. (*Revue General des Sciences*, vol. 27, No. 12, June 30, 1916.)—The old method of coating mirrors by the mercury process is a long, tedious, and unwholesome operation which has been nearly universally re-

placed by silvering. The latter method is, however, by no means perfect; the very thin film deposited by reduction of a solution of nitrate of silver is neither as white nor as brilliant as that of tin amalgam; it is deficient in strength, being detached by the slightest friction, and tarnished on exposure to sulphurous fumes. These faults are only very imperfectly overcome by a backing of varnish, of itself often a source of deterioration. Long ago an electrolytic deposit had been considered as a substitute, but experiments in this field yielded only mediocre results, whose irregularity was mainly due to the extreme thinness of the silver coating. Indeed, in the electrolytic method, it is this metallic film which consitutes the kathode, whose very minute cross-section is a poor conductor. When the contact is made around the periphery of the silvered glass, the electrolytic deposit takes place almost entirely in its immediate vicinity, and at points remote from the edges the thickness of the deposit diminishes rapidly, so that at the centre there is scarcely any deposit.

This drawback has been cleverly overcome by Delere, Gresy, and Pascalis, whose method is in actual use in Paris by the Compagnie des Glaces de Saint-Gobain. This process, styled "silvered protector" (French patent No. 444,710), consists in multiplying the number of current-carrying points of contact on the silver kathode by means of flexibly supported metallic combs. These combs have brass teeth, to each of which is attached a globule of tin, a soft metal which avoids scratching the silvering. All parts of the electrode immersed in the electrolyte are covered with an insulating layer of paraffin, with the exception of the points in contact with the silvering. The anodes consist of bands of pure copper supported between the contact points. The mirror to be coated is laid, silvered side up, in a shallow tray containing the electrolyte, the latter being kept of uniform strength by forced circulation. During the plating the current is interrupted every few minutes and the contact points shifted a short distance. The electrolytic action is thus uniformly distributed over the entire surface, resulting in a very homogeneous deposit of copper. Mirrors so protected resist the action of sulphurous fumes under the most unfavorable conditions and possess the unexpected advantage of increased reflecting power.

New Measuring Flume. ANON. (*Engineering News,* vol. 76, No. 6, August 10, 1916.)—Experiments made in the hydraulic laboratory at Fort Collins, Colo., by the United States Department of Agriculture have resulted in the development of a measuring flume which the experimenters believe promises to overcome the chief difficulties experienced in measuring water for irrigation purposes. The action of the device depends upon the adaptation of the Venturi principle to the flow of water in an open channel. The vertical sides of the flume for a short distance converge to a throat, and from that point diverge to its normal breadth, making it in

plan similar in contour to a Venturi tube. Gauge boxes are provided at the throat and at a point down stream for a measurement of the head.

The laboratory tests thus far made indicate that the device is quite accurate in its measurements. The Venturi flume is inexpensive and easily constructed and maintained. It automatically takes care of the velocity of approach and requires but little loss of head in the ditch. The increased velocity in the throat greatly reduces the danger of trouble from silt, sand, aquatic growth, or floating trash. The discharge through the flume is dependent upon the depth of water in the throat or the diverging section, as well as upon the difference of depths.

The Principles of Filtration. D. R. SPERRY. (*Metallurgical and Chemical Engineering,* vol. xv, No. 4, August 15, 1916.)—The process of filtration consists in separating the solids from a mixture of solids and liquid by causing the liquid to flow away from the solids through a porous mass, the openings of which are too small to allow passage of the solids. The porous mass, called the filtering medium, is composed of two parts: that which was provided in order that filtration might begin, called the filter-base, and that which was formed during filtration, called cake, consisting of solids which were too large to pass through the openings of the porous mass. At the beginning of filtration the filter-base comprises the entire filtering medium. As the flow proceeds the solids are deposited upon the filter-base, and the filtering medium now consists of the filter-base and deposited solids or cake. The flow of liquid through the porous mass and the building up of the porous mass are constantly changing because the liquid, as it flows into the cake, is continually leaving its solids behind, thus constantly increasing the thickness of the porous mass, while, simultaneously with this action, the liquid is continually decreasing its own rate of flow, due to the increasing thickness of solids through which it has to pass.

It is evident that if an expression can be derived showing the relation between the flow of the liquid and the building up of the porous cake and the laws of each determined, the two can be combined in a known relation, thus expressing the fundamental laws of filtration. Such an analysis of the two processes and a determination of their relationship leads to a formula for the total quantity of filtrate discharged in terms of time, pressure, and other known physical quantities of the materials employed.

The Dry Powder Fire Extinguisher. ANON. (*Quarterly of the National Fire Protection Association,* vol. 10, No. 1, July, 1916.)—Recent analyses made for the British Government show that dry powder fire extinguishers generally contain as their main constituent bicarbonate of soda, the amount of which varies from about 46 per cent. to 56 per cent. in the different samples examined. It is

true that bicarbonate of soda, on heating, gives off a certain quantity of carbon dioxide, but, in the opinion of the investigating committee, it is doubtful if the quantity generated has a materially effective influence on the action of the powder as an extinguisher, except possibly in cases of small fires of a special nature and limited extent. Water is far more effective than dry powder, the wetting of the surrounding material preventing the spread of the fire and thus confining its area. In the application of water, experiment showed that a given volume of water applied as a jet was decidedly more effective than the same amount applied by buckets. If the whole of the carbonic acid available on heating were given off suddenly, immediately the powder is strewn on the fire, approximately one cubic foot of gas would be formed for each pound of powder used. The smothering effect of this quantity of gas may be contrasted with that of the enormously larger volume of steam which would be generated by one pound of water, which gives over 25 cubic feet of steam at atmospheric pressure.

Water Power Could Not Displace Steam. E. WHITE. (*Coal Age*, vol. 10, No. 2, August 12, 1916.)—The town of Macon, Mo., is built over a bed of bituminous coal which ranges from 22 to 26 inches in thickness. Any resident in the city could sink a shaft in his back yard from 80 to 100 feet deep and be independent of the coal dealer.

When the Keokuk Power Company began reaching out for business, a subcontracting firm sent representatives to Macon with an offer to furnish the city and private consumers with electrical energy at 3½ cents per kilowatt-hour. This offer was also extended to neighboring towns. The section which the water power company proposed to supply was about 130 miles from the dam. The superintendent of the municipal power plant at Macon made some comparisons. He found that with coal-produced power he could undersell his big competitor over on the Mississippi River. With coal at $1.39 a ton in the bin and a plant of 400 horse-power, composed of two engines direct connected with generators, he discovered that, based on water-power rates, the coal-produced energy was saving the city $400 a month. He then went after the outside business in the same way that the hydro-electric company is doing, and closed contracts with the neighboring towns of Bevier and Callao for transmission of electric power. After a year's operation as a central power station, the Macon municipal plant has been able to show an annual profit of $5000 above operating expenses.

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THE VITAL RELATION OF TRAIN CONTROL TO THE VALUE OF STEAM AND ELECTRIC RAILWAY PROPERTIES.*

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THE railroads carry the life-blood of our society. They provide that circulation or communication between parts which is indispensable to the life of all organisms—physical, social, and economic. If circulation ceases, life also ceases; and the life of an organism is healthful in the same degree that the circulation is free and active.

The railroads are the arteries of our social order. To dispense with them and to depend entirely upon the smaller channels of transportation, such as wagons, motors, and, in this day of scientific farming, the tractor, would be to tax the capillaries of our body politic with the work of arteries and to result in mortal congestion. It is essential that the capacity of our system of railroads keep pace with the rapid growth of our institutions, that they may not atrophy and die.

The fact that the railroads have an importance to the social body equivalent to that of the vascular system to the human body should be enough to convince the public that it is as unwise to

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[NOTE.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

hamper and interfere with the operation of railroads as it is for a man to restrict the flow in his arteries.

The business of the railroad is to move trains. Therefore, the value of its right-of-way properties is in direct proportion to their capacity for the movement of trains. It has been well said that time is the essence of railroading; that is, the fundamental purpose of the railroad is to save time. To increase traffic capacity involves operating at higher speeds, and at more frequent intervals, trains of a greater number of cars, with greater carrying capacity. Increased traffic capacity means a greater number of ton-miles and passenger-miles per unit of time.

It goes without saying that an increase in the number of tracks of a railroad will enlarge its capacity, and enlarge it in greater proportion than the increase in the number of tracks, for additional tracks permit the segregation of traffic according to kind, and also prevent a tie-up on one track to tie up the whole line. Also, grade and curve reductions enable the running of longer trains at higher speeds, so far as getting trains into motion and keeping them there are concerned.

But to get the maximum volume of traffic out of any *set conditions of roadway* it is necessary to employ the most improved means of train control; that is, there is a vital relation between train control and the service which railway properties can render, and this service is the measure of their value.

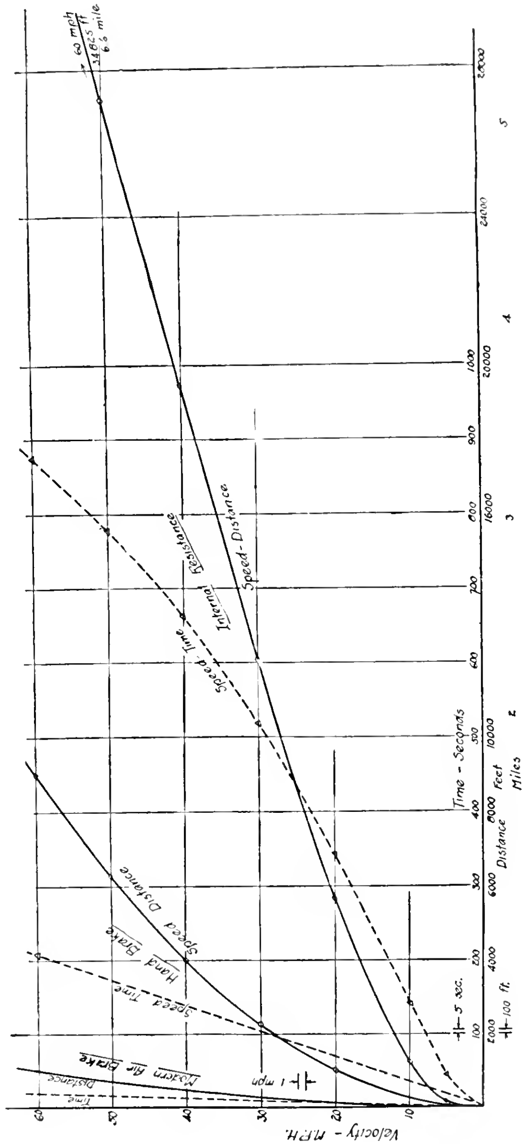
The relation of the wheel flange and the rail in providing *lateral* control to the movement of trains is a commonplace, and crosses the threshold into consciousness only when a broken flange puts a train into the ditch, with great loss of life and property. Similarly, the significance of longitudinal control, or, more simply stated, the ability to stop, does not receive the appreciation it merits. Naturally, were motion not imparted to a train, it would require no provision for control. To put a train into motion without adequate control would be more futile, not to mention the danger, than not to have moved the train at all.

Consider what the congestion in modern traffic would be were it necessary to remove all forms of hand and air brakes from existing equipment. Based on the results of experiments conducted on the Illinois Central Railroad by Prof. E. C. Schmidt, and confirmed by tests we have made, a passenger train stop from 60 miles per hour due to internal friction alone would require

FIG. 1.

DISTANCE AND TIME FOR PASSENGER TRAIN STOPS FROM VARIOUS SPEEDS.

COMPARATIVE PERFORMANCE OF TRAINS EQUIPPED WITH: NO BRAKE (INTERNAL RESISTANCE AFFORDING THE ONLY RETARDATION); THE HAND BRAKE; AND THE MODERN AIR BRAKE.



something over 30,000 feet—about six miles—as compared with 1000 feet, the stop distance for a passenger train equipped with the most modern brake, and a time of about 14 minutes, as compared with 20 seconds. Basing the headway upon the time required to run six times the stop distance, the modern trains with brakes could be operated at intervals of 1.14 minutes, compared with 34.1 minutes for the system of trains without brakes; that is, 30 trains run now where but one could run, lacking brake equipment.

Fig. 1 compares the performance in retardation of trains with and without control equipment. The stop from 60 miles per hour for the train without brakes is seen to be 34,825 feet instead of the conservative figure (30,000 feet) used above.

But in order to operate the two systems of trains with equal safety it would be necessary to run the train without brakes at a speed from which it could stop in the same distance as the train equipped with modern brakes. This speed would have to be about nine miles per hour in order that the train might come to a stop in 1000 feet. This lower speed permits, of course, reduced headway, amounting, on the above basis, to 7.6 minutes. If now the velocity in miles per hour is multiplied by the number of trains per hour for each system of trains, a comparison of train-miles per hour can be made. This is 3150, compared with 71 train-miles per hour, or a traffic capacity 44 times greater for the system of trains using the air brake—the increase being due to that one thing alone, viz., the use of modern air brake equipment.

Overlooking the fact that the stop from nine miles per hour with the train lacking brake equipment requires 125 seconds, as compared with 20 for the stop from 60 miles per hour with the air-braked train, and taking the average time between terminals as inversely proportional to the maximum speeds above considered, it would take 133 hours, or 5½ days, to ride from New York to Chicago on this train, instead of the usual 20 hours.

Without the use of brakes it would be impossible to operate trains over any grade exceeding ten feet to the mile. At this point a stop would be indefinitely prolonged and the time between trains correspondingly increased. Consider, if you can, what it would mean to our railroads if they had to carry grade reduction to the point of having two-tenths of one per cent. as the maximum permissible grade!

And, finally, the element of flexibility, or ability to apply any part of the total range of braking effort at the desired moment, comes up for the comparison which baffles numerical illustration. It can be said, however, that the train without braking effort other than that of internal resistance has this braking effort all on all the while, and it can be modified only by applying accelerating effort. The modern air brake, on the other hand, permits all degrees or gradations, up or down, of braking effort, from the very minimum needed to slow down or stop from low speeds to the very maximum needed in an emergency while running at high speeds. Imagine the degree of skill necessary on the part of an engineman in handling a train without brakes to "spot" baggage, a coal chute, or a water tank, involving, as it would involve, variations in grade, curves, train resistance, etc.

Comparing the effectiveness of the hand brake with that of the modern air brake, it is found on the foregoing basis that about eleven trains can be run, equipped with the latter, to every one equipped with the hand brake, the stop distances being 9000 and 1000 feet, respectively, from a speed of 60 miles per hour. Putting the two equipments on the same stop basis, viz., 1000 feet, the maximum speed permissible for the hand-braked train is 20 miles per hour, and the traffic capacity for a system of such trains is 363 train-miles per hour, as compared with the 3150 established above for the air-braked trains, or nine times less. It would take 60 hours to travel from Chicago to New York, or the distance would be virtually increased three times, viz., from 1000 to 3000 miles.

All of this is based on having a brakeman at every wheel and ready to do his part at the appointed time. In this light, it is seen that the service stopping distance would be shorter than the emergency, because in the latter the surprise, or lack of preparedness, element would lengthen the dead time obtaining at the beginning before the brakes could be started into action.

Picture the number of brakemen which would be required to handle our modern passenger, and particularly our modern freight, trains; and also the lack in flexibility afforded the engineman in making stops at desired points, and in controlling a train down a mountain whereon it is necessary to make allowances for changes in grade, curvature, and other local conditions. There can be no team work equal to that possible in one player only—no coördi-

nation like that found in a single man—and the control of a train concentrated in one person, with the corresponding concentration of responsibility, is the ideal condition, due regard being given, of course, to any and all practical provisions for a "watchman to watch the watchman." The fireman in the cab, the "dead-man's" device for electric traction service, the conductor's valve on the train, and the automatic stop and cab signal are some to be properly mentioned in this connection.

Having attempted to sketch briefly the tremendous importance of adequate control for the movement of trains, provided by the modern air brake, to the question of traffic capacity, which is of such pressing moment to every railroad manager, it is well to turn to the financial phase of the matter. In other words, is the investment in modern brake apparatus a paying investment? Does the return warrant the expenditure?

Using American railway statistics for the year 1914, the average *per diem* mileage for each freight car is 24.5, and the average load per car, involving loaded and empty car movements, is 13.9 tons. The revenue per ton-mile—the cost to the consumer of the railroad's product—is the astonishingly low figure of 0.733 cent, a rate unequalled by any other nation on the face of the globe. The product of these three figures gives $2.50 as the daily revenue for each car. An annual depreciation and maintenance charge of 4 per cent., added to 6 per cent. for the interest on the investment, gives a total of 10 per cent., which, applied to an average cost of $40 for the air brake equipment per car, results in a daily charge for this equipment of 1.095 cents. This is but forty-four one-hundredths of one per cent. (0.44 per cent.) of the daily revenue which the brake makes possible, a revenue which, without the brake, would drop to five cents per day or less with the same ton-mile charge, instead of the above $2.50, due to the fact that the ton-mileage per car would be cut forty times; that is, it would take forty cars without the brakes to do the work of one car equipped as at present, theoretically speaking. Practically considered, it is impossible to say how much the unit costs per ton-mile would be raised if the brake were dispensed with, for the features of necessary grade reduction, lack of flexibility and safety, make it absurd to attempt an estimate.

However, using the same basis, it is found that an additional investment for brakes of 4 per cent. of the value of a car, using

$1000 for the latter, increases its capacity forty-fold. In other words, an investment of $40 corresponds to an alternative investment of 39 times $1000, or $39,000. Assuredly it requires no marked business acumen to choose between these alternatives!

It may be advanced that other countries, using brakes which do not even approximate ours in efficiency (to say nothing of the cases where automatic brakes are not used at all), are getting along; are hauling freight every day, and are keeping trains in motion pretty well generally. I wonder if they are also aware of the fact that, despite greatly reduced labor costs, the ton-mile rates elsewhere are a number of times greater than ours. This is of great concern to us, for, in the last analysis, a difference in freight rate of one dollar per ton for a certain haul may mean two or three times this amount before the bill reaches the ultimate consumer—not the shipper, but the consumer of the article shipped. And, after all, the final economic burden always rests upon the commonwealth.

In his discussion of Mr. J. S. Y. Fralich's paper on "Freight Car Brake Installation," presented before the Western Railway Club last December, Mr. W. E. Symons illustrates in a striking manner the comparative values of the air brake equipment and the life and property which it safeguards. He says:

"In estimating the value of the train (Twentieth Century, 18-hour train) with 200 passengers, on the usual legal estimate of passengers, the train and its contents would be worth $1,157,000, and the brakes on the train would be worth approximately $2255, which is a little less than two-tenths of 1 per cent. (0.195 per cent.)."

Insurance has developed wonderfully of recent years into an exact and indispensable science—an institution which wholesomely establishes more firmly every day that economic equity towards which we shall and must come some day. Did you ever consider the air brake in relation to insurance? Suppose we assume that each full train equipment mentioned by Mr. Symons makes 150 trips per year between New York and Chicago. This is a very conservative estimate, providing, as it does, ample allowance for terminal lay-overs for cleaning, maintenance, etc. The average *per diem* value of the train must then be taken at $150/365 \times \$1,157,000 = \$475,000$, as it takes approximately one day for each trip. It is difficult to say where the line should be drawn between

the insurance charges for the air brake and the service or traffic charges, because the insurance arises in the potential or *latent* power of the equipment to make an emergency stop when the necessity arises, and therefore practically all the wear and tear comes in, and should be charged to, ordinary service. Using, however, the liberal allowance of an annual charge of 4 per cent. for depreciation and maintenance and 6 per cent. for interest on the investment, the total of 10 per cent. gives a daily charge on $2255, the cost of the brake equipment, of almost 62 cents. This is 13 one-hundred-thousandths of 1 per cent. (0.00013 per cent.) of the train value—quite a remarkable insurance rate, all will agree. Even if multiplied 100 times in order to include everything involved in the operation of the train, such as signal systems, etc., it still remains an unusually low rate.

Of course, safety appliances are in the nature of preventive insurance, for in event of a wreck there is no reimbursement for the damage. It is about as difficult to exactly estimate the insurance value of the air brake to transportation by rail as it is to estimate that of the compass to transportation by water. It may seem startling to liken the worth of the air brake to that of the compass, but it is true that each is indispensable in its own service. And it may be even more startling to say that the brake is of greater value than the compass. This is not so extreme, however, when one reflects that practically all the tonnage handled by water is also handled by rail, and that much tonnage is carried by rail which has nothing to do with water shipment. In other words, transportation by rail is the more important because there is more of it.

The hazard for transportation by rail calls for a rate of about 1.25 per cent. in the insurance world. The better insurance comparison then would be to compare this with the rate which would be demanded in event that all railway equipment were stripped of its air brake apparatus. The rate would jump so high and to such an uncertain figure that in all likelihood no insurance company would be willing even to consider such a proposition.

Up to this point the most extreme conditions have been contrasted in order that the present stage of railway science may be measured as nearly as possible on an absolute scale. All intermediate degrees of comparison may be had according to the development stages which are compared. To provide for the making of comparisons in greater detail and to facilitate an accu-

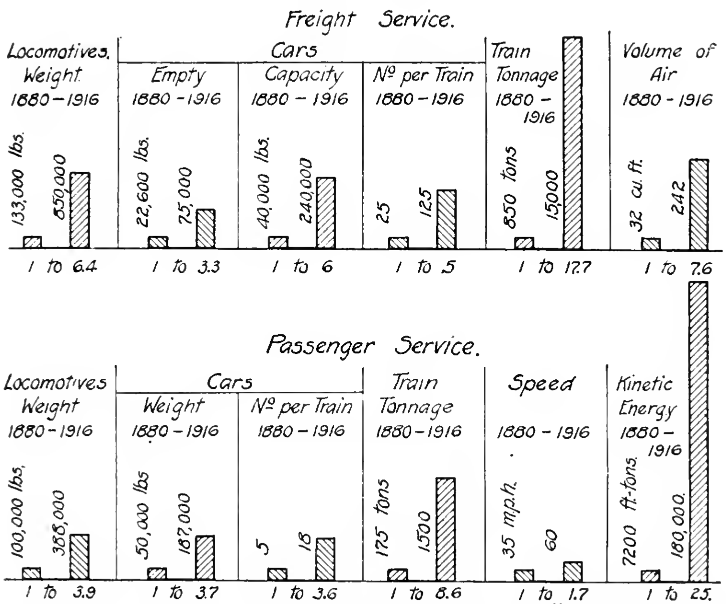
rate analysis of all the factors and their limitations for maximum traffic capacity an outline has been prepared which the subsequent portion of the paper will follow.

FIG. 2.

COMPARISON OF RAILROAD OPERATING CONDITIONS.
1880 – 1916.

Freight Service	1880	1916
Locomotives - lbs	133,000	850,000
Cars – lbs.	22,600	75,000
Capacity	40,000	240,000
Nº per train	25	125
Train tonnage	850	15,000
Volume of air - cu. ft.	32	242

Passenger Service	1880	1916
Locomotives - lbs.	100,000	388,000
Cars - lbs.	50,000	187,000
Nº per train	5	18
Train tonnage	175	1500
Speed - m.p.h.	35	60
Kinetic energy, ft-tons	7200	180,000



Operating conditions in 1880 differed quite materially from those of to-day. New problems require new solutions. To stop a modern passenger car from 65 m. p. h. in 25 seconds requires 1920 brake horse-power and certainly brake apparatus improved over that used on the coach of 1880 to give 149 brake horse-power for a corresponding stop from 35 m. p. h.

Before examining this outline, first consider briefly some of the changes that have occurred in operating conditions on our railroads. The contrast between conditions obtaining in 1880 and those now demanding ever more and more careful and scientific consideration is graphically portrayed in Fig. 2.

The outline for the balance of the paper now follows:

TRAFFIC CAPACITY FACTORS AND THEIR LIMITATIONS FOR MAXIMUM TRAFFIC ON STEAM AND ELECTRIC RAILWAYS. RIGHT-OF-WAY CONDITIONS CONSTANT.

CAR UNIT

Factors	Determined and limited by

Car capacity	Length of car:
	  Clearances on curves.
	Width:
	  Clearances.
	Height:
	  Clearances.
	Weight:
	  Rails and road-bed.
	  Bridges.
	  Contrast between empty and loaded weight—dead weight per ton of lading.
	  Volume of air for control.
	  Brake shoe duty.
	  Draft gear capacity.

Car loading (average percentage of possible capacity realized)	Coöperation on part of shippers. Reduction of empty haul. Grouping of l.c.l. lots.

Per diem mileage	Terminal facilities for:
	  Loading.
	  Unloading.
	  Maintenance.
	Demurrage.

Maintenance	Organization. Cost.

TRAIN UNIT

Factors	Determined and limited by

Train length (number of cars)	Locomotive capacity:
	  Single shoe brake rigging.
	Length of sidings.
	Station platform length—electric railways.
	Train control:
	  Slack action:
	    Serial brake action.
	    Electro-pneumatic brake.
	    Uniform braking ratio.
	    Impact—slid flat wheels.
	    Foundation brake gear.
	    Brake cylinder pressure regulator.
	  Grade service.
	  Volume of air:
	    Release of brakes.
	Draft gear capacity.

Time of station stops	Car door arrangement and capacity for ingress and egress.
	Station arrangement.
	Local conditions as to number of passengers to load or unload.
	Picking up and setting out cars:
	  Making up trains in rapid transit service.
	  Automatic car, air and electric couplers.

TRAIN UNIT—*Continued*

Factors	Determined and limited by
Delays to trains	Terminal facilities: Trains getting into or out of yards. Defective or inadequate equipment.

Acceleration	Locomotive equipment—steam railways.
	Motor equipment—electric railways:
	  Line-voltage regulation.
	  Regenerative braking.
	  Selective relays for empty and loaded conditions of motor car.
	  Number of motors and trailers in train.
	Train resistances:
	  Foundation brake gear.
	Grade.

Maximum speed	Acceleration.
	Station spacing.
	Retardation:
	  Electro-pneumatic brake.
	Grade:
	  Running control.
	  Stops.
	Curves.

Retardation	Maximum speed.
	Weight of car:
	  Volumes of air.
	  Brake shoe duty.
	  Difference between empty and loaded condition.
	Foundation brake gear.
	Number of cars—shocks due to serial brake action.
	Air brake equipment.
	Rail conditions.
	Regenerative braking.

SYSTEM OF TRAINS

Factors	Determined and limited by

Headway or spacing of trains	Safety:
	  Retardation.
	  Maximum speed.
	  Installation and characteristics of signal apparatus.
	  Acceleration.
	  Length of train.
	  Time of station stops.
	  Speed control devices.
	  Local roadway conditions:
	    Station spacing.
	    Curves.
	    Grades.
	    Interlocking plants.
	    Bridges.
	    Junctions, etc.

This outline is grouped according to the car unit, the train unit, and the system of trains.

THE CAR UNIT.

The part the car unit plays in deciding maximum traffic capacity depends upon: 1st, what it can carry; 2nd, the extent to which this total lading is realized during all movements of the car; 3rd, the daily mileage the car makes; and 4th, the condition in which it is maintained.

CAR CAPACITY.

The length, width, and height of the car govern the load it can transport, and these in turn combine to establish the total weight of the car. Right-of-way clearances limit all these dimensions.

Clearance limitations on curves dictate as to the length of the car. If the distance between truck center plates is increased, the center of the car on the inside of the curve approaches the clearance limit set for way structures. If the length, or overhang, beyond the center plates is added to, the danger of fouling comes on the outside of curves and the additional requirement arises that the couplers must have increased swing. This in turn means that new equipment will not couple satisfactorily with the old, so far as operation on curves is concerned. The new 67-foot cars for the New York Municipal Railway probably represent the maximum for electric traction service. Pullman cars have come to a length of 82 feet from the 50-foot passenger coach of 1880. The freight car has more severe conditions under which to operate in the way of sharp curves on industrial sidings, and 44 feet mark its limit—which, however, contrasts well with the 28-foot car of 35 years ago.

The width and height of all vehicles must, of course, conform to tunnels, bridges, and various road structures. Right here the reminder may be made of how simple many problems would be if we could only start anew without having to conform to old limitations—such as introducing the six-foot gauge, with clearances to provide for the future development of centuries, and all things to correspond. The most difficult problem the railway engineer has to solve is the one of interchange and conformity with existing equipment and conditions.

The weight of rolling stock can be no greater than the rails and supporting road-bed and bridges will warrant. The advent of heavy motive power in the way of Mallet, Sante Fé, Mountain,

Mikado, and other types of locomotives has brought about the strengthening and replacement of bridges and the laying of heavier rail. If an average axle load of 65,000 pounds (which ranges far above and below this, due to the effect of reciprocating parts) is permitted for a locomotive, it would certainly seem that 50,000 pounds could be permitted for a freight car where low speeds and the lack of need for riding qualities do not introduce other considerations. As a matter of fact, a railroad in the Southeast is contemplating the use of freight cars which when loaded will have an axle load of about 53,000 pounds. Of course, the tax a load imposes depends upon its frequency as well as its quantity, and therefore it is to be expected that a train of heavy axle loads would more severely burden the rail than a train with the great axle load on the locomotive only. The rail is the limiting factor for wheel loads, and it has been nip and tuck for the makers of steel rails to keep pace with the recent increases in wheel loads. The bridge is the limiting factor for the total weight of vehicle, and it must be remembered that a bridge strengthened to sustain successfully a single Mallet locomotive and cars of the usual weight might not be able to handle two or three locomotives together, or a locomotive and a train of cars each of which approaches the weight of a locomotive.

The freight cars above mentioned will weigh about 315,000 pounds loaded, which is the weight of our "largest" locomotives of a few years ago. The lading capacity is to be 245,000 pounds, which makes the ratio between the loaded and empty weights 4.5, or, viewed in another way, the dead weight per ton of lading is 571 pounds. For the 40,000-pound car of 80,000 pounds capacity, hailed as the latest word but a few years ago, the ratio of loaded to empty weight is but three; that is, there are 1000 pounds of dead weight for every ton of lading.

This decrease in dead weight with relation to lading capacity and also the greatly increased total capacity of the modern freight car display a significant trend in the reduction of unit costs on the part of our more and more efficient American railways. It also displays an operating condition correspondingly difficult, for the contrast between the empty and loaded weight has become so great that former brake apparatus—fully able to care for the wide range of operation through which it has served so long—has now become quite inadequate. A curious inconsistency is encountered in the

expectations some people have concerning the permanence and range of brake equipment, designed for operating conditions of 20 years ago, to continue with unchanging efficiency, and in their unquestioning discard for all time of the wooden underframe and the draft gear of archaic capacity.

The braking ratio for a brake installation is defined as the nominal relation between the brake shoe pressure, equal on each wheel, and the weight each wheel imposes upon the rail. If all wheels are not braked, or not braked equally, it is taken as the relation between the sum of all brake shoe pressures and the total weight of the car.

The "single capacity" brake is the one most generally found in railroad service to-day. It is one in which a constant braking force is used for all conditions of car loading, which results in a widely varying braking ratio. If a freight car is braked at 60 per cent. of its empty weight, on a cylinder pressure of 50 pounds, and the ratio of loaded to empty weight is three to one, the braking ratio for the loaded car becomes 60/3, or 20 per cent., the cylinder pressure basis still remaining 50 pounds. With a loaded to empty car weight ratio of 4.5 to 1, the loaded car braking ratio drops to 60/4.5, or 13.3 per cent. The brake installation must base the braking ratio on the empty weight of the car, and not higher than 60 per cent. Otherwise, if this 60 per cent. were based upon the loaded weight, the empty car braking ratio would be raised to a point prohibitive because of the far more violent running of slack and the slid flat wheels it would produce in long trains.

This greatly lowered braking ratio for the loaded freight car means two things: *First,* it means that trains of such cars cannot be controlled down a great many of our main line—to say nothing of our branch line—grades without resorting to either greatly restricted train lengths, the operation of empty cars in the train in order to provide the additional braking effort needed, or the use of an empty and load brake which maintains a more nearly constant braking ratio by varying the braking forces in accordance with the loading of the car. *Second,* it means that violent slack action in trains of loaded cars mixed with empties is much more certain to occur, with its inevitable damage to lading and equipment. For slack action arises in and is proportional to the variation in retardation between the different cars in a train, and

the retardation of each car is a direct function of its effective braking ratio.

The increased total weight of each vehicle is also of great significance here. Many ask why it is that to-day shocks in train operation occur with the magnitude and frequency unknown a few years back. For the same velocity difference between two cars in a train the severity of impact will depend directly upon the car weights—the heavier the cars the greater the impact. Other things being equal, the 70,000-pound car will give almost twice the shock obtaining with the 40,000-pound car. This is a partial answer to the question. The balance is found in increased velocity differences due to greater train lengths, which will be discussed under "Train Length and Serial Brake Action."

The new motor cars for the New York Municipal Railway are built to accommodate 260 passengers, making an increase of 35,000 pounds from the empty weight of 85,000 to 120,000 pounds loaded. This represents a loaded to empty weight ratio of 1.41—quite insignificant when compared with the ratios found in freight service. But in a municipality like New York trains are run "on the second," and it is essential, for the sake of maximum traffic volume, to have retardation at all times independent of the condition of car loading, and, of course, an empty and load brake is required. This is quite apart from the questions of control on grades and slack action in trains, because the weight ratio is so small as to render the former negligible and the electro-pneumatic brake circumvents any difficulty from the latter.

The empty and load brake equipment for these motor cars is so arranged that a constant braking ratio is had for all conditions of car loading, and brake flexibility is also maintained; which is the ability to graduate braking effort on or off in any desired series of steps between maximum and minimum. This is the ideal operation, but the apparatus necessary to obtain this highly desirable result is, at the present stage of the air brake art, a refinement quite out of keeping with the features of modern freight service. The difference between the empty and loaded weight of the steam road passenger coach is so comparatively slight that demands are not encountered similar to those of very dense interurban traffic..

In this connection, viz., the relation of live load to dead weight, digress for a moment to consider the comparative transportation revenues per ton-mile for passenger and for freight service. The

average capacity for all freight cars is about 40 tons (39 tons in 1914), and the average light weight probably 20 tons, or one-half the capacity. This makes the actual ton-mile rate for the total weight $40/60 \times 0.733$ cent (the net ton-mile rate for 1914), or 0.49 cent. In passenger service, on the other hand, this rate is 0.31 cent per ton-mile—determined by estimating a load of 100 persons on a seven-car train which weighs 735 tons complete, and a passenger-mile rate of 2¼ cents. Thus the passenger rate is but thirty-one forty-ninths, or 63 per cent. of the freight rate, despite the fact that the cost of handling passenger trains is far in excess of that for freight trains, due to fast schedules and the many conveniences demanded by the travelling public.

In the passenger empty and load brake the selective mechanism is thrown into engagement by the opening of the car doors. Before the car doors are shut passengers have been discharged and taken on, and the car loading is that under which operation will take place until the next stop is made. Closing the car doors disengages the selective mechanism to save it from wear and tear and from cutting in and out due to inequalities of track. One portion of this device is attached to that part of the truck which keeps it at a constant distance from the rails. The other portions are connected to the car body, and relative motion between the two—a function of the movement of the truck springs and, therefore, of the car weight—provides that base for the variation of volumes and valves which gives the desired result. This device also operates selective relays which provide a current supply to the motors so proportioned to the weight of the car that acceleration, as well as retardation, is constant, irrespective of the condition of car loading.

Without this means for providing uniform retardation the headway and schedule of trains, to the extent that they are dependent upon retardation, would be impaired 40 per cent. during loaded car movements—which, of course, constitute the critical phase of train operation.

The empty and load brake for freight service employs two distinct braking forces, due to the operation of one or of two brake cylinders during brake applications. The full service braking force obtained with the one cylinder is 60 per cent. of the empty weight of the car, as in the case of the single capacity brake. It is used with the empty and partially loaded car. But when the

car is loaded one-half or more the second brake cylinder is cut into action to assist the first, making the total braking force 40 per cent. of the weight of the fully loaded car, instead of the 13 or 15 per cent. with the single capacity brake. Where the situation permits it is most desirable, for the sake of uniformity, to use a braking ratio of 40 per cent. for both the empty and loaded car. This braking ratio provides ample control on grades; does away with the slack action due to differences in braking ratio through the train, and minimizes the effect of serial brake action in causing the running of slack, as will be shown in the discussion on "Train Length."

Increased car weights have called for larger brake cylinders and larger reservoirs, the increased volumes of which in turn have taxed the ability of the air-handling devices to conform to the time limits required for proper train operation. Compare the 10-inch equipment of the 50,000-pound passenger car of 1880 and its auxiliary reservoir volume of 2500 cubic inches with the modern Pullman requiring two auxiliary and two supplementary reservoir volumes aggregating 52,000 cubic inches. When it is remembered that the brake pipe which connects the equipments throughout the train has not been increased in size, the need for air brake devices of a design which will not overtax the capacity of the brake pipe to supply air from the locomotive becomes increasingly significant. The empty and load freight brake cuts down the air requirements for train control to one-half that now required by the equipment in most general use. This is equivalent to a valve gear on a locomotive which would do the same work as the existing type with a demand on the boiler for only one-half the steam now required.

The eight-wheeled coach of 1880 had as many brake shoes through which to dissipate the kinetic energy of the moving trains of that time as the eight-wheeled coach of to-day. But the weight of the coach has since more than doubled, thereby doubling the horse-power or duty of each brake shoe. Speeds have also increased, which means that brake shoe duty has increased as the square of the speed. Contrasting the 50,000-pound coach of 1880, running at 35 miles per hour, with the 150,000-pound Pullman of to-day, running at 65 miles per hour, the horse-power required to effect a stop in 25 seconds is 149, as compared with 1540, or, dividing this total by the number of shoes in each case, the duty

for each shoe, formerly 18.6 horse-power, has become 128.3 horse-power, or 6.9 times greater. Is there any wonder in the need for an efficient type of clasp brake, which, among a number of other important advantages, employs two brake shoes per wheel, thereby halving the load per shoe and returning the shoe more nearly to the temperature at which it can do its most efficient work? Where a set of brake shoes in a certain service lasts but 10 days with the single-shoe-per-wheel type of brake gear, a full set of shoes will last with the clasp brake 28 days, instead of the 20 days to be expected with a doubled number of shoes. If worn to the thinness that halving the brake shoe load permits, the set of brake shoes will last 33 days, as compared with 10 for the single shoe brake. This points to a great possible saving in brake shoe maintenance, as well as the more obvious one of shoe material, because a car repairer can replace 10 shoes on a car in practically the same time he can replace 5 on the same car, the preparatory measures being such a great proportion of the total effort required in each case.

The capacity of a car will, or should, depend on the capacity of the draft gear to absorb shocks. Naturally, as the weight of vehicle increases the draft gear will be called upon to perform greater service when the same velocity differences are set up between cars in stopping with brake equipment of outdistanced capacity, and in starting with locomotives of greatly increased tractive effort. Of course, all the punishment will in mixed trains come on the cars and draft gears of relatively small capacity, and if, during the transition period, these are to be spared, it will be necessary to employ the most modern train control equipment.

CAR LOADING.

It is idle to provide marvellously improved carrying capacities of the car unit by employing steel construction, etc., and then not utilize it. The extent to which this full capacity is realized when loading a car is of great significance from the standpoint of operating economy. Campaigns are being waged by various railroads to awaken the shipper to the necessity for loading cars to their full capacity and thereby assist himself as well as all others to reduce car shortages. Live stock and bulky freight of small weight prevent the utilization of full capacity as do l. c. l. (less-than-carload) shipments. The latter will be grouped to better advantage

as improved systems for so doing are evolved and put into practice.

Of course, the reduction of the empty haul increases the average load for the car. With every superintendent of transportation this problem of routing cars to cut down the empty haul is a live issue.

The application of the empty and load freight brake dispenses with the hauling of empty cars back and forth over mountain grades in order to provide the necessary braking control by keeping the average tonnage per brake to the predetermined safe figure; and as mountain grades are usually the "necks of the bottle" for the flow of railroad traffic, these "necks" are restricted by every empty car used for the purpose for which it was never built; namely, that of providing adequate control for the lading of *other* cars.

Inasmuch as only 10 to 15 per cent. of the total life of a freight car is spent in actual transit, gleaning the revenue-producing ton-miles, improvement in terminal facilities are highly desirable to provide means for more promptly loading and unloading cars and for making inspection and repairs—light or heavy as facilities permit—simultaneous with the handling of lading. Demurrage charges are being more and more scientifically established to penalize carelessness and lack of coöperation on the part of shippers in needless detention of cars as storehouses.

The traffic capacity of the car unit is indissolubly involved in the ever-present problem of maintenance, and this in turn is dependent on the factors of organization and cost. In general it is true that if maintenance charges are stinted depreciation charges will jump. The ideal is, of course, that point for each where the total is a minimum and where if either one or the other is raised or lowered the sum will increase in amount. In only too many cases, unfortunately, is it true that a penny-wise and pound-foolish policy prevails in greatly reducing maintenance work and in suffering the more than proportionately increased depreciation unconsciously, because it resembles, and really is, "indirect taxation." What is not seen and not known gives small concern.

Maintenance and service are inseparable, however, even where neglected maintenance does not cause an immediate increase in depreciation. For example, to disregard a leaky brake cylinder packing leather does not mean greater depreciation of the brake apparatus; but, so far as service is concerned, the brake equipment

might as well be entirely dispensed with if the elaborate means for putting air in the cylinder are unsupported by adequate means for keeping it there.

THE TRAIN UNIT.

TRAIN LENGTH.

Needless to say, train length, or the number of cars hauled in a train, is a vital factor in the matter of maximum traffic capacity.

The maximum train length will depend on the locomotive capacity, for the available tractive effort should be such as to start a train without the necessity for the "taking of slack" so violently as to endanger on each occasion the integrity of the train. In passenger service the single-shoe-per-wheel type of foundation brake rigging is responsible for highly increased train resistances, which mark a needless loss in locomotive capacity and also in fuel and water consumption of from 30 to 35 per cent. in many cases. This was revealed by the results of the brake tests made on the Lake Shore and Michigan Southern at Toledo in 1909. The reasons for this will appear in the discussion of "Foundation Brake Rigging."

The length of sidings or passing tracks will also govern the length of trains on single-track lines, the only exception being where trains of maximum length never need to pass one another, the only "meets" of such trains being with trains of inferior lengths, where "sawing by" is resorted to. The final limiting value of the inferior train length must not be more than twice the length of the siding. In such a case, however, the "sawing by" becomes so very much involved that the practical operating limit for the inferior train length will be the siding capacity. In some respects this factor of siding length should appear under the division "System of Trains," for a single train alone considered involves no element of passing track length.

For electric railways the length of the station platform frequently determines the permissible length of trains, for obviously passengers cannot enter or alight from cars standing beyond the platform. A very important feature of the reconstruction of some of the New York subways has been the extension of station platforms to permit the running of longer trains.

Unfortunately for our reputation for statesmanship, legal limits have been established in some cases for the number of cars to be permitted in a train, but it is to be hoped that the sense of

reason and fair play among our people will soon prevail on their representatives not to apply artificial restrictions on the arteries of commerce and handicap society as a whole to just that extent.

SLACK ACTION.

But the element of train control is probably the most significant of all factors in this problem of train lengths. Consider first the question of serial brake action, or the behavior of brakes on individual cars in sequence and in relation to the train as a whole. When an ordinary pneumatic brake application is started at the front end of the train the first car is the first to experience brake action, and each car follows from the head end to the rear, according to its position in the train, the brake on the last car being the last to apply. The time between the application of the brake on the first and that on the last car is called the "time of serial action." For any given type of air brake equipment this time varies with the length of train. Therefore, when a brake application is started the first car will have had its speed reduced, before the brake applies on the last car and before the slack in the train runs in, by an amount proportional to the severity of the brake application, to the total amount of slack in the train, and to the time of serial action.

The severity of the brake application, or, in other words, the rate of retardation set up, depends upon the brake cylinder pressure realized; the basic cylinder pressure for the nominal braking ratio; the nominal braking ratio; and the efficiency factor. This may be briefly summed up in mathematical form—

$$R = \frac{p}{C} P\ ef$$

Where:

R = the retardation factor, in per cent.;
P = the nominal braking ratio, per cent., based on
C = the basic cylinder pressure for P, pounds per square inch;
p = the effective cylinder pressure, pounds per square inch;
ef = the efficiency factor.

By the retardation factor (R) is meant the relation of the actual retarding force to the total weight of the vehicle. It is a measure of the rate of retardation. A retarding factor of 100 per cent. obtains when the retarding force equals the weight of the

vehicle, or, in other words, when the retardation is equal to that due to gravity—32.2 feet per second per second, or 22 miles per hour per second.

As before noted, the nominal braking ratio (P) is the ratio between the total nominal brake shoe pressures on the wheels of the car and the weight of the car. It is a "nominal" braking ratio, because it makes no allowance for losses in the transmission of the brake cylinder force, by the multiplying, or leverage system, of the foundation brake gear, to the normal or perpendicular brake shoe pressure on each wheel.

The basic cylinder pressure (C) assumed to be in the cylinder when the braking ratio is established, is taken as the nominal pressure arising from a full service, or an emergency, brake application, according as the service braking ratio or the emergency braking ratio is in question. For the service braking ratio this pressure is 50 pounds with freight brake installations and generally 60 pounds for passenger equipments.

The actual pressure (p) realized in the cylinder depends on the brake pipe reduction made, the piston travel, and cylinder packing leakage. For the purposes of computation and comparison, it is necessary to deduct 5 pounds from this pressure, especially when it is relatively low, to give the *effective* pressure, because it will take about 5 pounds to compress all release springs and place the brake shoes against the wheels ready to "start business." For the higher cylinder pressures—35 pounds and more—this deduction may be neglected and the $e \times f$, or efficiency, factor be made to compensate for release springs, etc.; that is, for the lower pressures the efficiency factor, flexible like the cloak of charity as it is, cannot be made to cover the proportionately great sin of this initial loss. In other words, the efficiency factor cannot conveniently be made a function of cylinder pressure in addition to one of speed and type of foundation brake rigging.

The efficiency factor ($e \times f$) is the combined product of the brake rigging efficiency (e) for transmitting and multiplying the cylinder force into normal brake shoe pressure, and the coefficient of brake shoe friction (f), which is the measure of the tangential force acting on each wheel in relation to the normal brake shoe pressure. It is not possible, nor is it necessary, to separate these two factors for the purposes of computation. The combined product is the connecting link between the actual average re-

tarding force which must have been acting to effect a given stop distance obtained in actual service and the nominal brake shoe pressure determined by multiplying the brake cylinder pressure by the piston area and the leverage ratio of the brake rigging.

Now look again at the expression for the measure of, or the rate of, retardation:

$$R = \frac{p}{C} P\ ef$$

If p, P, or ef be singly or severally raised or lowered in value, R will be correspondingly raised or lowered. If C be raised, R will be lowered, and *vice versa*. Thus it will be seen that if the actual cylinder pressure (p) be high, due to a heavy brake pipe reduction having been made, or to short piston travel, the retardation will be correspondingly high; and if this pressure be low, due to a light brake pipe reduction, long piston travel, reduced auxiliary reservoir volume, or leakage, the retardation rate will also be low.

If the braking ratio (P) be high, as, for example, 80 per cent. on a freight train, the retardation set up on the head end of the train in a certain time will be twice that with the braking ratio equal to only 40 per cent., other things being the same.

And, finally, if the efficiency factor (ef) be low, as it is at high speeds, due to the variation in coefficient of shoe friction, the retardation will be low as well, and *vice versa*, for low speeds. Thus if the efficiency factor be 8 per cent. for a speed of 50 miles per hour, the retardation set up at the head end of a train will be approximately half that where the efficiency factor equals 15 per cent. for a speed of 12 miles per hour.

If the amount of slack movement between the cars in a train is increased, more time is given for the cars first experiencing brake action, or experiencing the more severe brake action, to retard before the other cars close in or pull away, as the case may be. Therefore, the velocity difference between cars will depend on the amount of slack in the train, being greater as the slack is greater, though not in direct proportion. It is easy to see that if there were no slack or possible relative movement between the cars in the train there could be no difference in velocity set up between them. Carrying this to the other extreme, it can be imagined that the slack could be so excessive that the last car in the train might be entirely stopped before the slack had closed in. Thus there

will be no shock where the slack is zero, and there will be no shock where the slack is sufficient in amount to permit all the cars to come to a stop before this slack runs in. This upper limiting value of slack necessary to avoid shock will vary with the braking characteristics (rate of retardation and time of serial action) and with the initial speed of the train. Somewhere between these limiting values of slack there will be a point at which the maximum shock can occur, all other factors but the one of slack remaining constant. This critical value of slack for maximum shock (the maximum, of course, being different for each condition) tends to become greater as the speed is higher, as the time of serial action is longer, and as the rate of retardation is less. It is obvious that as the length of train is increased, so also is the total amount of slack.

The foregoing means that in making a brake application there is a critical speed for maximum shock, due in a measure to resonance in slack surging and to the grouping of various vehicles in the train. Variations from this critical speed at the time of applying the brakes, together with favorable positions and amounts of slack, account for the fact that severe shocks do not occur with *every* brake application in service where they do appear more or less frequently.

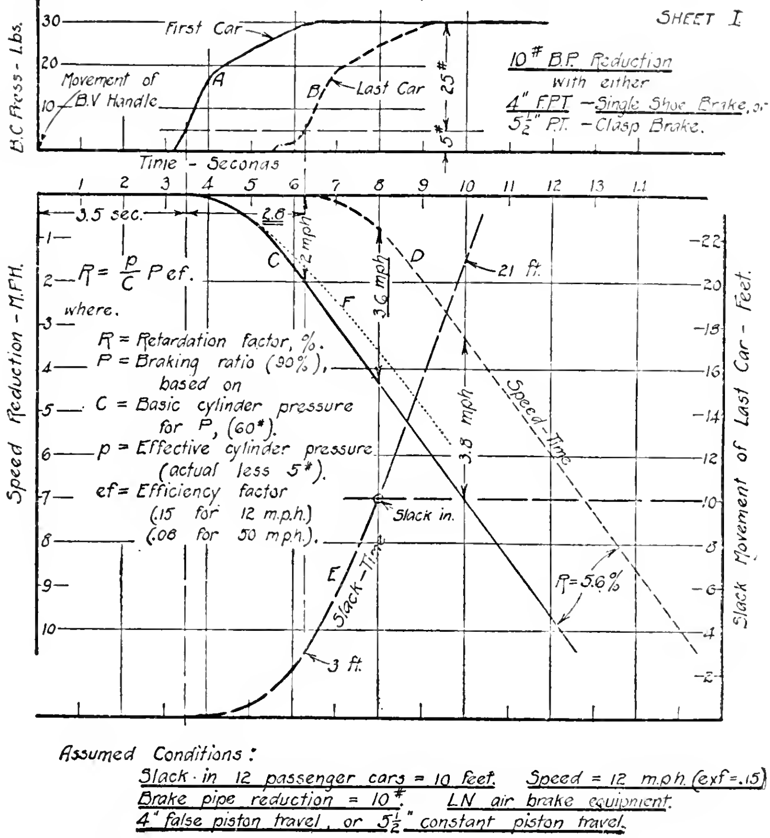
However, the amount of slack is of no moment if the time of serial action be zero, as with the electro-pneumatic brake. Here the last brake starts to apply as soon as the first, for all the brakes go on as one. As the time of serial action is increased the dangers due to slack action also increase. Increased time of serial action means increased opportunity for greater retardation on the head end of a train before the slack closes in. It is clearly seen that the time of serial brake action is directly proportional to the length of train.

Refer to Figs. 3, 4, 5, 6, and 7 for graphical illustration of all these points. On Fig. 3, curve *A* is that of brake cylinder pressure on the first car. It shows that the pressure begins to rise at about 3.2 seconds after the brake valve handle is moved to application position, and 0.3 second later it passes the 5-pound point, at which it is assumed that the brake shoes have been brought just against the wheels. Retardation on the first car then commences, and as time continues the speed of the car is more and more reduced, as shown by curve *C*. Retardation increases in rate as

cylinder pressure builds up until the maximum is reached at a little after 6 seconds' time. The slope of curve *C* represents the rate of retardation—as the slope is steeper the retardation, or change in velocity for a certain time, is greater. Curves *B* and *D* are

FIG. 3.

ILLUSTRATING RUNNING OF SLACK IN TRAINS DUE TO SERIAL BRAKE ACTION.



The delay in application of the last brake in a train permits the head brake to effect greater retardation than the last before the slack runs in. In general, the less the slack the less the retardation difference, and therefore the less the shock will be.

similar curves for the last car, the serial time being shown as 2.8 seconds; that is, the brake on the last car got into operation 2.8 seconds later than did the first. Curve *E* is one representing the relative, or slack, movement between the first and last car, due to the differences in retardation. This movement is equal to the

average velocity difference between the two cars multiplied by the time during which the average difference occurs.

Curves *C*, *D*, and *E* neglect the cars intervening between the first and last, and assume a condition equivalent to the removal of the intervening cars, a separation of the first and last car equal to the total slack in the train, and a retention of the time of serial brake action, as with all the cars in place. This assumption is not true to actual conditions, for the reason that as each of the intervening cars closes in on the one ahead it boosts along the bunch ahead at a speed somewhat higher than shown by curve *C*—possibly something like dotted curve *F*. However, as each successive car closes in on the bunch ahead the impact accelerates the increasing mass ahead less, and more of the sudden changing in velocity must be done by the colliding car, so that the retardation of the first car does not differ materially from that shown by curve *C*. Moreover, as each successive car collides with the bunch ahead the velocity difference increases until it is a maximum when the last car closes in. This means that as the shock runs back the bunch of cars ahead becomes increasingly solid, so far as the draft gears are concerned, until the last car has a veritable stone wall with which to collide. And, finally, as it is not known just what a certain velocity difference means in the force of an actual blow between two cars or one car and a group of cars, an allowance for discrepancies may be made in the velocity difference which it is assumed the draft gear can care for without appreciable shock.

If there be 10 feet of slack in the train, as shown in Fig. 3, this slack will be all in, 8 seconds after the brake valve movement, and the velocity difference between the head end (which includes the last car but one) and the last car is 3.6 miles per hour. After the impact the train as a whole moves on with a velocity a trifle higher than that represented by curve *C* at the instant of impact, as explained in connection with curve *F*. Curves *C* and *D* are shown heavy to the instant of impact of the last car, for 10 feet of slack. They are continued with lighter lines in order that the influences of other conditions of slack may be compared. For any actual case, the impact causes curve *D* to drop down and be merged with curve *C*, which is slightly raised. Dispensing with this geometrical parlance, this can be stated otherwise by saying that the front portion of the train and the rear car move on with the same velocity after impact, retarding together.

If the amount of slack in the train be cut down to three feet and the time of serial brake action remain unchanged, the velocity difference is seen to be but two miles per hour. With 21 feet of slack the velocity difference is 3.8 miles per hour, an amount not materially different from that for 10 feet of slack. Thus it is seen that *the less the slack in the train the less the velocity difference between the head end and rear, and, therefore, the less the shock.* However, after a certain point, about nine seconds here, when curves *C* and *D* become parallel, due to the cylinder pressures being the same on head end and rear, the velocity difference is the same, irrespective of the amount of slack. The retardation for curves *C* and *D* is 5.6 per cent. It must be remembered that where the speed is such as to permit the head end to stop before the rear end runs in, an increase in the amount of slack tends to decrease the severity of the shock—other things remaining equal—in that more time is afforded the rear end for retardation. This was pointed out in a foregoing discussion.

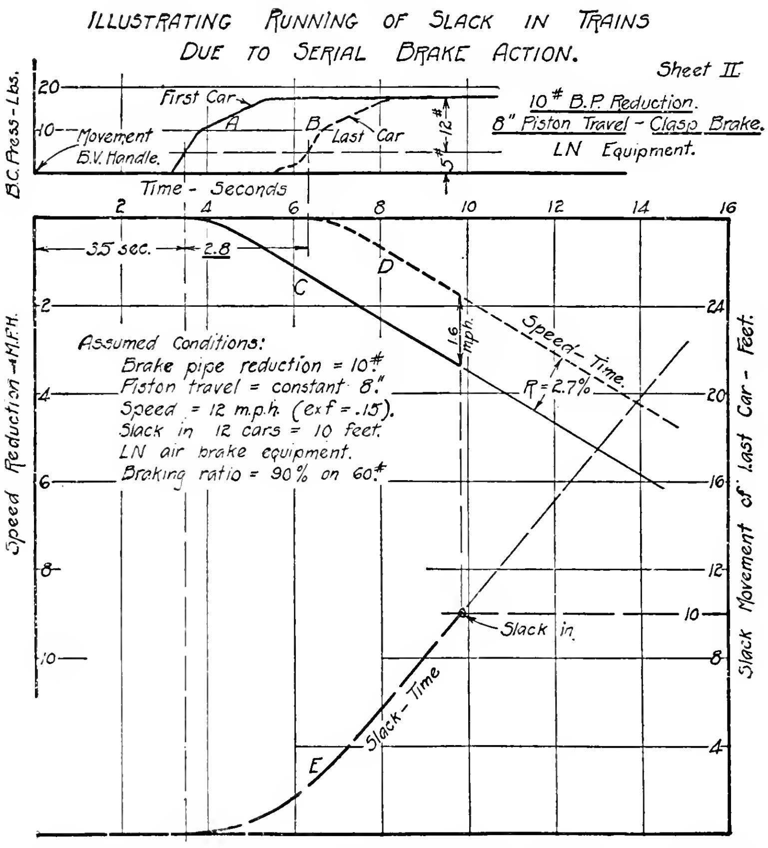
Remember, in this connection, that where variable conditions of braking ratio, piston travel, or cylinder leakage are scattered indiscriminately through a train, causing local differences in retardation to be set up, there can be, in general, no violent slack action, for the reason that the amount of slack intervening between two extreme conditions is probably limited to that of a few cars. It takes *cumulative slack action* to cause shocks. For that reason a freight train equipped with the single capacity brake and made up of empties and loads in alternate order would handle very smoothly, whereas, with the usual train make-up of all loads at one end and all the empties at the other end of the train, shocks of great severity must be expected. Obviously, it is impracticable to switch empties and loads into alternate order in making up trains.

Compare the results of Fig. 3 with those of Fig. 4. Here a retardation of but 2.7 per cent. is effective, due in this case to a lower brake cylinder pressure, and the velocity difference between head end and rear, for the same serial time of 2.8 seconds and the same total amount of slack of 10 feet, is proportionately reduced to 1.6 miles per hour; that is, *the less the retardation used until the slack closes in, the less severe will be the shock*, the amount of slack and serial time remaining the same. As before noted, this lessened retardation rate may be due to reduced cylinder pressures,

reduced braking ratio, or reduced coefficient of brake shoe friction due to higher train speeds; and the reduced cylinder pressure may be due to a lengthened piston travel or to a light brake pipe reduction.

This explains why it is so necessary to make light brake pipe

FIG. 4.

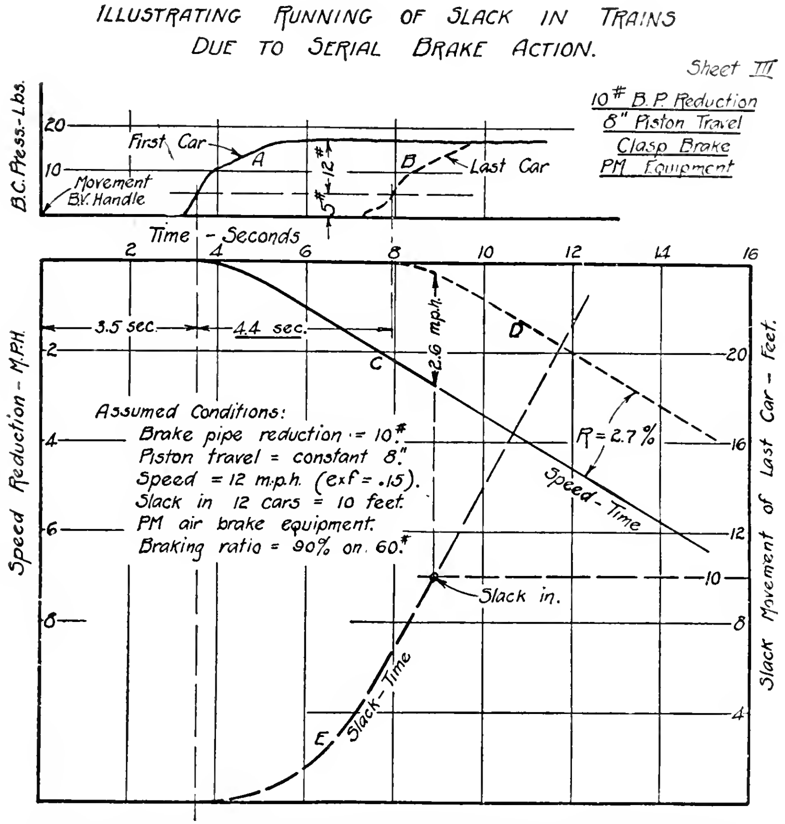


Compare with Fig. 3. With a certain time of serial action, the lower the rate of retardation set up the less will be the velocity difference between head end and rear when the slack closes in. This shows why brake applications on long trains must be started with a light brake pipe reduction.

reductions in applying the brakes on long trains at low speeds and why it is so necessary to have piston travel not too short, but of the proper length. This in turn explains the necessity of having foundation brake rigging which will not permit a material increase in piston travel as the cylinder pressure is increased, because the

slack adjuster, in making the travel proper at 8 inches for full cylinder pressure, throws back the piston position for the lighter pressures; that is, the cylinder pressures for light brake pipe reductions are far in excess of what they should be, due to the shortened piston travel. This variation or increase in piston travel between

FIG. 5.



Compare with Fig. 4. Increased time of serial action due to type of air-brake equipment or to number of cars in the train means increased velocity difference between the head and rear ends of the train and shocks of corresponding intensity.

that for the five or ten pounds pressure necessary to bring the shoes just against the wheels, and the full service pressure of 50 or 60 pounds, is known as "false" piston travel. In the discussion on "Foundation Brake Rigging" this will be described to better advantage.

Fig. 5, when compared with Fig. 4, illustrates the effect of the

time of serial brake action on shocks in a train. This time is here 4.4 seconds, as compared with 2.8 seconds on Fig. 4. The retardation is the same in each case (2.7 per cent.), and also the slack (10 feet), but the velocity difference is 2.6 miles per hour instead of 1.6; that is, *the severity of the running of slack is directly proportional to the time of serial brake action.* It is easily seen that in bringing the curves *C* and *D* of Fig. 4 closer together, as compared with Fig. 5, by reducing the time element, the velocity difference and, therefore, the shock intensity, is reduced.

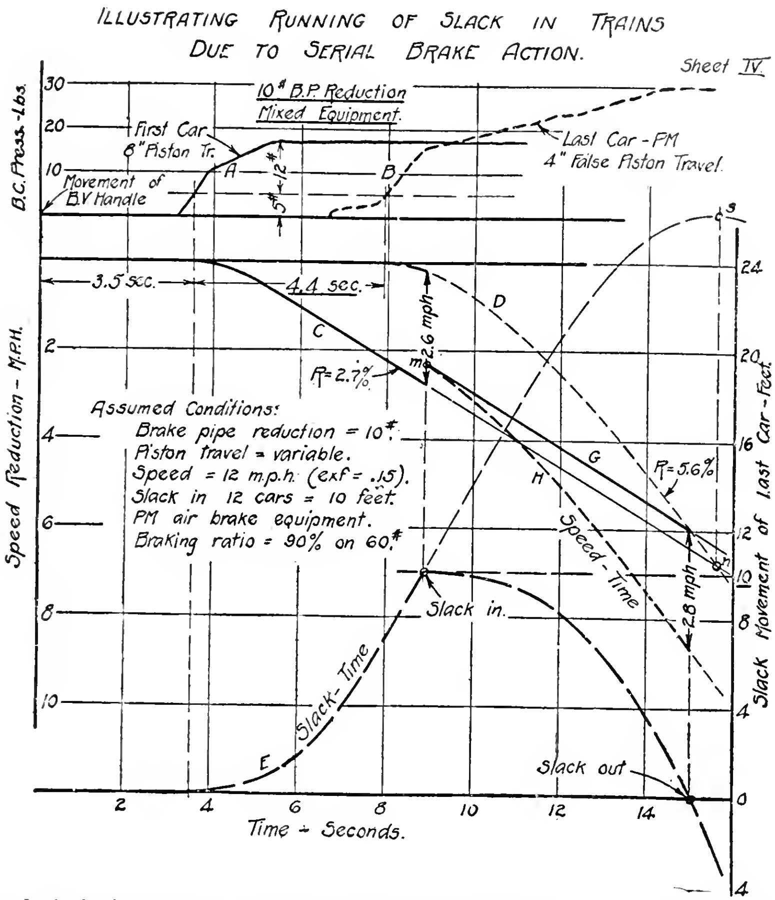
Remembering that as cars are added to a train the time of serial action is correspondingly lengthened, it is readily appreciated that brake apparatus entirely suitable for trains of short length (the standard of yesterday) cannot serve the more severe operating conditions and demands of the lengthened train of to-day. Thus the reduction in serial time for 12 cars from the 4.4 seconds in Fig. 5 to the 2.8 seconds of Fig. 4 (resulting in a reduction of velocity difference from 2.6 to 1.6 miles per hour) is due to the introduction in the triple valve of the quick-service feature whereby the brake pipe reduction is started at the brake valve and continued locally at each triple valve in a serial manner through the train, each triple valve venting a bit of brake pipe pressure to the brake cylinder and thereby starting the next triple valve into action more promptly. Without the quick-service feature it is necessary to make the entire brake pipe reduction at the brake valve.

In this problem of serial time the advantage of a suitably designed foundation brake rigging which will insure a constant piston travel for all cylinder pressures now appears. With such a rigging a brake pipe reduction may be made in sufficient amount (seven pounds should be the minimum) to guarantee the release of all triple valves, without creating a brake cylinder pressure of more than 10 or 12 pounds. This results in very slight retardation, and the slack closes in with small velocity differences and, therefore, negligible shocks. The slack may not be all in by the time the second brake pipe reduction is started, but the triple valves are now in service lap position and the drop in brake pipe pressure required to move the triple pistons alone, instead of the pistons and slide valves together as when the first reduction was made, is comparatively slight. That means that the time of serial action is greatly reduced; and likewise the velocity differences by the

time that the small amount of slack remaining closes in. The final result is an absence of any noticeable shocks.

Fig. 6 represents a combination of mixed conditions in the train. A comparatively small retardation is set up on the head end

FIG. 6.



Lack of uniformity in retardation due to differences in cylinder pressure or in braking ratio may cause a surging of slack, first in one direction and then in the other. This shows why the Empty and Load Brake makes more certain the smooth handling of long trains. Uniform piston travel and tight cylinder leathers contribute to the elimination of surges or slack action.

(2.7 per cent. here), due in this case to proper piston travel and a correspondingly light cylinder pressure. Due to "false" piston travel, and consequent high cylinder pressure, the retardation on the rear end is great (a final value of 5.6 per cent.). This same

condition can, and does, occur when the cylinder pressures are uniform but the braking ratio on the head end is low and that on the rear end is high, as in the case of load carrying mail, baggage, express, or refrigerator cars, and double-heading locomotives on the head end of passenger trains, or as in the case of a freight train with loads ahead, empties behind, and lacking an empty and load brake equipment.

As here shown, when the 10 feet of slack has run in, the velocity difference between head end and rear is 2.6 miles per hour. The impact decreases the speed of the last car almost instantly to some point *m*, and raises the speed of the front portion of the train to this same point. From here the differences in retardation cause the first and last cars to slow down, as portrayed by curves *G* and *H*, respectively. The 10 feet of slack then runs the other way, due to the fact that the brakes are acting so much more effectively on the rear end, and a jerk is experienced with a velocity difference of 2.8 miles per hour. With this condition a shock is had "going and coming."

If the amount of slack is great enough, or the time of serial action small enough, to permit curves *C* and *D* to cross (which means that the two ends of the train are running at the *same* speed at that instant) as at some point *n* without the slack closing in, no buffing impact will be had and the slack will start to run the other way, as shown at *s*, because the rear end is running at speeds ever lower than the head end as time goes on. The jerk will be correspondingly worse, however, if the slack be increased, unless the train be stopped before the slack runs completely out.

Now multiply the situation pictured in Fig. 6 by a number of times corresponding to the relation it bears in length of train (slack and time of serial action) to the modern freight train and wonder why it is that delays in transit, repairs to rolling stock, and loss and damage claims total the enormous figure they do on American railroads to-day. Is it any wonder that the empty and load brake was developed to overcome that exceedingly bad condition of having loaded cars on the head end braking at 15 per cent. and the empties at the rear with a braking ratio of 60 per cent.? If the positions of the empties and the loads be reversed there would be no jerk, but there would need to be none, for the run-in or buff would buckle the train practically every time the brakes were applied, due to both the mass and the low braking

ratio of the loads on the rear end. The rôle and purpose of the empty and load brake in making uniform the braking ratio, and likewise the retardation on the empty and loaded cars, can, therefore, be well appreciated by the resulting decrease in rough handling of trains and damage to lading and equipment.

You will appreciate, I am sure, that my endeavor is to point out what are the causes of unsatisfactory results in train control: results such as improper or neglected adjustments, deficient maintenance, manner in which trains are made up, in some cases inadequate train control, and improper manipulation on the part of the operator. What I desire to impress upon you most forcefully is that these undesired results are not inherent in the operation of trains, as unfortunately seems to be the impression of some people—for adequate train control apparatus is obtainable, and realization of its full value requires only a comprehension and application of the principles underlying its service.

Fig. 7 illustrates the significance of the electro-pneumatic brake in the question of train lengths. With electro-pneumatic control there is *no* time of serial action for *any* length of train. The brakes on all cars go on as one, and the curves *A* and *B, C* and *D* of Figs. 3, 4, 5 and 6 are merged into one. Irrespective of the condition of slack or rate of retardation, there can be no slack action, for all cars retard alike. This means that a brake of *any effectiveness* can be used without any loss of time in applying it and without fear of the running of slack in the train and resultant rough handling. This presupposes, of course, that the braking ratio and piston travel are uniform throughout the train, a condition which it is reasonable to require.

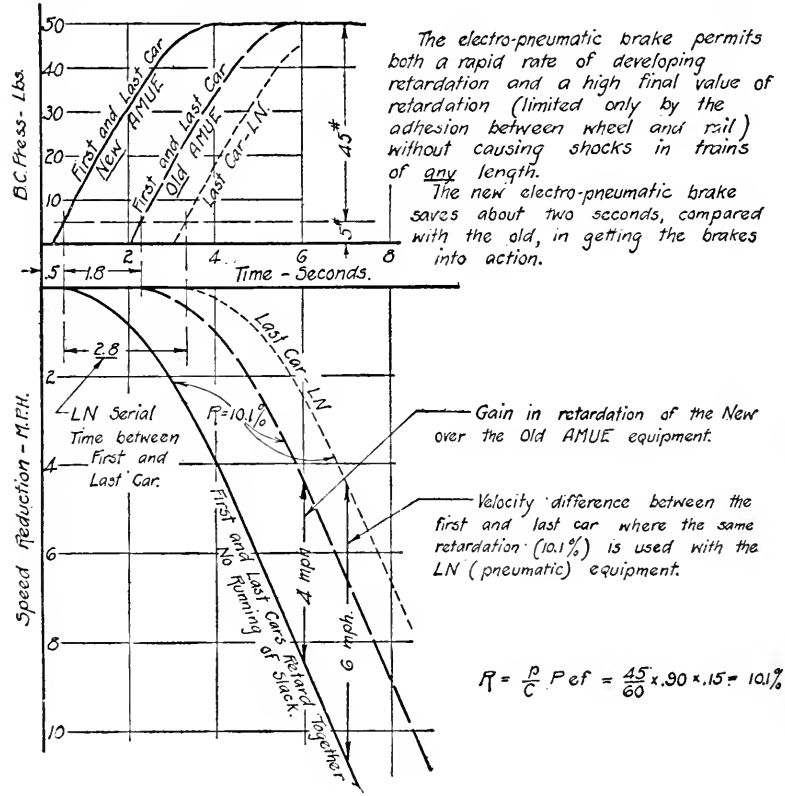
Fig. 3 shows a delay of 3.5 seconds from the movement of the brake valve handle until the brake on the first car becomes effective, and a further delay of 2.8 seconds until the last brake accomplishes anything. These delays are due to the time required for air to flow from the brake pipe, for triple valve parts to move, and for air to flow from the auxiliary reservoir to the brake cylinder. Fig. 7 shows for the old electro-pneumatic equipment (AMUE) a delay of only 2.3 seconds from the operation of the brake valve to the application of all the brakes on the train. This application is effected by simultaneously reducing with an electromagnet the brake pipe pressure locally on every car. The delay, or dead time,

is due to the movement of the triple valve parts in sequence, and the flow of air from the auxiliary to the cylinders. The newly evolved electro-pneumatic brake, however, cuts down this dead time

FIG. 7.

CHARACTERISTICS OF THE OLD AND NEW ELECTRIO-PNEUMATIC BRAKE.

COMPARISON OF THE PNEUMATIC WITH THE ELECTRO-PNEUMATIC BRAKE.



Cutting down the time of serial action to zero by employing the electro-pneumatic brake entirely removes slack action for *any* rate of retardation and for *any* amount of slack. It is necessary, however, to have the braking ratio and piston travel uniform throughout the train.

The best brake—the entire train considered—is the one which, in affording the best rate of retardation, creates the least velocity differences between the various vehicles in a train.

to half a second by eliminating the necessity for the movement of the pneumatic parts of the triple valve and by cutting down the time for the flow of air from the auxiliary reservoir to the brake cylinder. The advantage of this saving may be grasped by noting

that at the end of six seconds from the movement of the brake valve the train equipped with the new brake is running a little more than eight miles per hour slower than the initial speed ,and four miles per hour slower than the train with the old electro-pneumatic brake; also, this is seven miles per hour slower than the first car of the train equipped with the straight pneumatic brake (see Fig. 4) where the maximum retardation is used consistent with tolerable shock conditions. Bear in mind that with the electro-pneumatic brake it is not a question of *tolerable* shock, but one of *no shock whatever.*

Just to convey some idea of what it would mean to use with straight pneumatic equipment a rate of retardation equal to that (10.1 per cent.) shown for the electro-pneumatic brake on Fig. 7, dotted curves have been added to represent the performance of an LN pneumatic equipment on the last car of the train of Fig. 3. The retardation curve for this is separated from the one used to represent the first car (new AMUE) by a time of 2.8 seconds, the serial time shown in Fig. 3. The velocity difference between head end and rear is seen to be *six miles per hour.* Does not this make clear the relation between train control devices and the ability to run longer trains more smoothly and with less loss of time?

From the foregoing it will be clear that, notwithstanding the greatly increased train weights and lengths of recent years, brake development has kept at least an equal pace with the requirements of adequate train control. The capacity of modern brake apparatus is far from exhaustion, the only consideration being that proper engineering be employed in the choice of brake equipments for the conditions to be met and due care be exercised in its installation, with particular reference to the maintenance of proper volume proportions. As to volume relationships, however, more will be said under the division "Foundation Brake Gear."

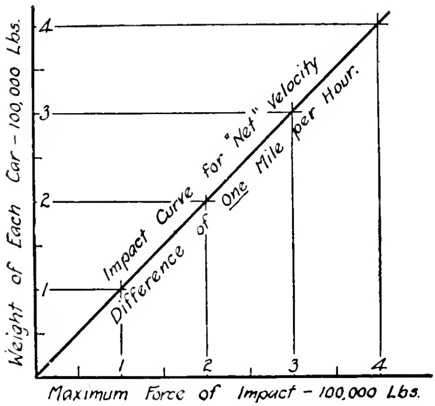
IMPACT.

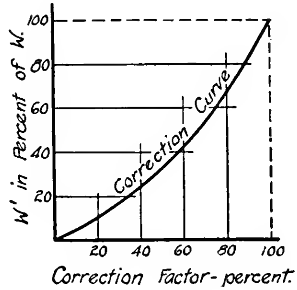
So far impacts have been spoken of in terms of velocity difference only. Fig. 8 has been prepared to show what the actual force of impact may be. *This curve shows that for each net velocity difference of one mile per hour the maximum blow due to impact is equal to the weight of one of the colliding vehicles.* If the net velocity difference be twice this, or two miles per hour the blow

will have twice the intensity; if three miles per hour, three times the blow, etc. By "net" velocity difference is meant the actual velocity difference less one mile per hour, which is a rough-and-ready allowance to give for the capacity of a draft gear. This, of

FIG. 8.

MAXIMUM FORCE OF IMPACT BETWEEN TWO CARS.





If the two cars are of unequal weights: find the force of impact for two cars equal to the larger in weight (W). Multiply this force by the correction factor from curve.

With Inelastic Impact as Basis (Coefficient of restitution = 0):

$$F_a t = \frac{MM'}{M+M'}(v - v')$$

where

M, v = Mass $\left(\frac{W}{g}\right)$ and velocity (ft. per sec.) of one car.

M', v' = " $\left(\frac{W'}{g}\right)$ " " " " " " second "

F_m = Maximum impact force.

F_a = Average impact force during period of impact.
= $.76\ F_m$

t = period of impact = .03 seconds.

$(v - v')$ represents a "net" velocity difference (actual minus one) of one mile per hour.

The maximum force of impact is proportional to the net velocity difference. If the latter is 2 M.P.H instead of 1 M.P.H. the impact forces will be double those given above, etc.

For every mile per hour "net" velocity difference (actual difference less one) the force of the impact due to one car colliding with another is approximately equal to the car weight.

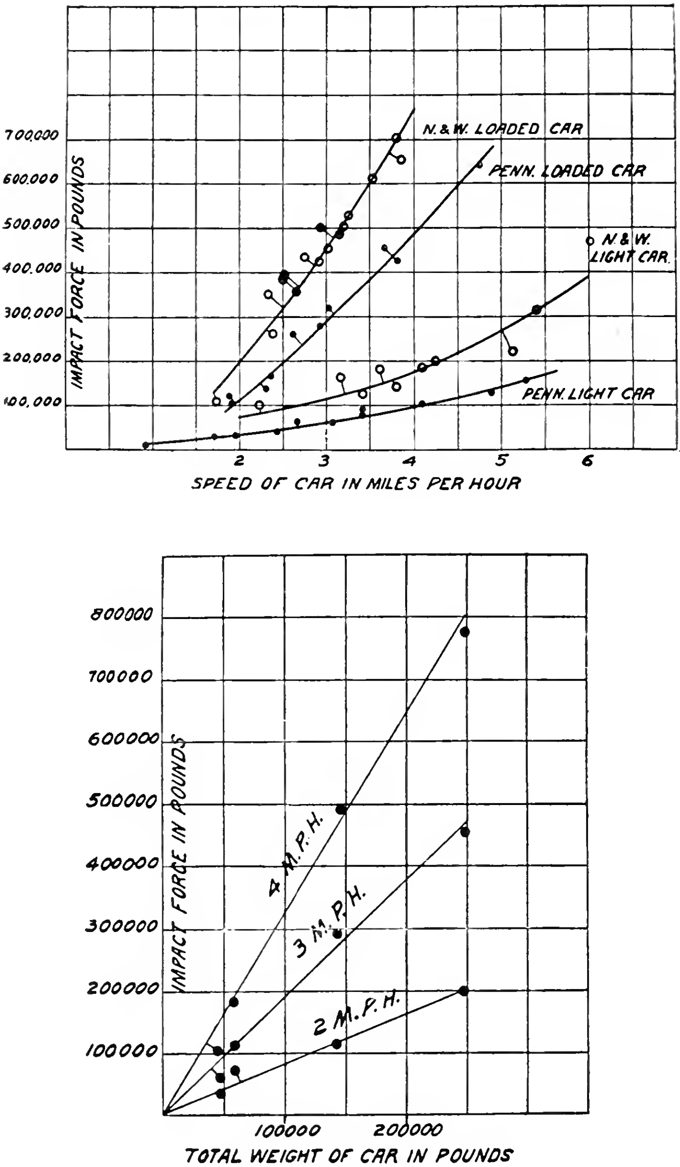
course, will vary with the weight of vehicle and the characteristics of the draft gear. A net time of 0.03 second has been assumed as the total period of impact. By "net" time is meant the time of impact, neglecting the part played by the draft gear, which has been sufficiently allowed for in determining the net velocity differ-

ence. In other words, the "net" time for impact is started from some point in the last stages of draft gear action. In establishing this impact curve it is assumed that the *average* force of impact (F_a) for the net impact period is equal to 76 per cent. of the maximum force (F_m). This factor conforms to the results of the very elaborate and scientific tests conducted by Lieut.-Col. B. W. Dunn on "A Photographic Impact Testing Machine for Measuring the Varying Intensity of an Impulsive Force," and reported by him in this JOURNAL for November, 1897. According to him, the limiting values of this factor are 0.637 and unity.

The correction curve on Fig. 8 provides for determining the impact when the two colliding vehicles are of unequal mass. To use it, assume that both cars agree in weight with the heavier and find this maximum blow in the regular way. Then, by noting the weight of the lighter in percentage of the heavier, find from the correction curve the impact in percentage of the maximum blow first found. For instance, suppose the net velocity difference between an 80,000-pound car and one weighing 100,000 pounds to be one mile per hour. The blow for two 100,000-pound cars would be 100,000 pounds. The lighter car is 80 per cent. of the other in weight; therefore, the blow between the two as shown by the correction curve is about 88 per cent. of that for two cars weighing as much as the heavier, or 88,000 pounds. If a car collides with a "solid" string of ten or more cars equal to the first in weight, the force of impact is double that obtaining when one of these cars collides with another only, with the same velocity difference. By "solid" is meant the removal of all slack between the cars due to the couplers being solid, so that the bunch acts as one continuous vehicle. In case two "solid" groups of cars collide a proportionately modified allowance must be made for the draft gear capacity.

The values given in Fig. 8 agree quite closely with the results of careful impact tests made with freight cars by Prof. L. E. Endsley and reported by him in the *Master Car Builders' Proceedings* for 1915. Fig. 9 is a copy of the plotted results of his tests. As a significant check on the arbitrary deduction made for determining the net velocity difference for Fig. 8, note that the curves in the upper chart of Fig. 9, if continued, would pass through the base line at approximately one mile per hour. Reading from the lower chart, it is seen that for a total velocity differ-

FIG. 9.



Force of Impact Between Freight Cars.

Results of impact tests made by Prof. L. E. Endsley.

ence of three miles per hour (net difference of two according to the above basis) a 200,000-pound car gives 375,000 pounds—almost 400,000—as the force of impact. According to Fig. 8, the impact would be 400,000 pounds.

SLID FLAT WHEELS.

The relation between impacts, due to slack action in trains, and slid flat wheels is not as apparent as it should be if due appreciation is to be given to the causes for the acute and chronic suffering of our railroads from this form of damage to equipment. Wheels slide because the fulcrum (or pivot about which the wheel moves with relation to the rail) at the point of rail contact fails; that is, the demand on the rail in the way of thrust exceeds the adhesion or static friction between the wheel and the rail. A buff or jerk in the direction of motion of the train increases the car velocity and the rotative speed of the wheels. A certain thrust on the wheels is required of the rail to increase their angular velocity. If the brakes are applied this rail thrust due to impact is augmented by the thrust set up by brake shoe friction. The sum of the two thrusts must not exceed the adhesion if the wheels are not to slide. If this total does exceed the adhesion, the car is said to be "knocked off its feet." An impact opposite to the direction of train motion neutralizes the rail thrust due to braking, but may carry the thrust beyond in the other direction up to the limiting value of adhesion, with like result, only the impact required to do this must be correspondingly greater than the first. In other words, the total rail thrust is equal to the algebraic sum of the thrust set up by the impact and that caused by braking.

The impact "knocking the car off its feet" lasts a very short time only, and the rail thrust brought into play by this impact lasts only as long. But brake shoe friction in this very short interval of time has jumped up in value, becoming static in nature where it was kinetic before, and the wheel-rail friction has dropped in value, becoming kinetic where it was static or rolling before, and the wheels may continue to slide. The continued sliding of the wheels depends upon these changes in value of shoe-wheel and wheel-rail friction being sufficient to make the former greater than the latter. This will, in turn, depend, of course, on the relation of the shoe pressure to the weight on the wheel and the condition of the surfaces of the shoe and rail. Where sliding does persist—

and it is only too often—it may be said that the impact has "knocked the car off its feet" and brake shoe friction holds it "off its feet."

As a numerical illustration: A freight car weighing 50,000 pounds has an adhesion of 3125 pounds per pair of wheels if the adhesion factor is 25 per cent. A cylinder pressure of 29 pounds gives 690 pounds brake shoe friction per pair of wheels for a braking ratio of 60 per cent., based on 50 pounds cylinder pressure and an efficiency factor of 15 per cent. An impact of 200,000 pounds will bring the total rail thrust up to the above adhesion limitation. A greater braking force, a greater impact (which is not unusual in service), or a reduced adhesion will result in the car being "knocked off its feet" by the impact. If the brake shoe friction at this instant exceeds the wheel-rail friction, the car will be kept "off its feet." This will be true if the rail friction drops to 1250 pounds (10 per cent.) and the shoe friction doubles to 1380 pounds (efficiency factor rising to 30 per cent.), due to the respective changes from static to kinetic friction, and *vice versa*. Under the same conditions an impact in the opposite direction must exceed 300,000 pounds to knock the car off its feet. This impact computation is based upon two 700-pound wheels on a 500-pound axle, having a combined moment of inertia of 143.

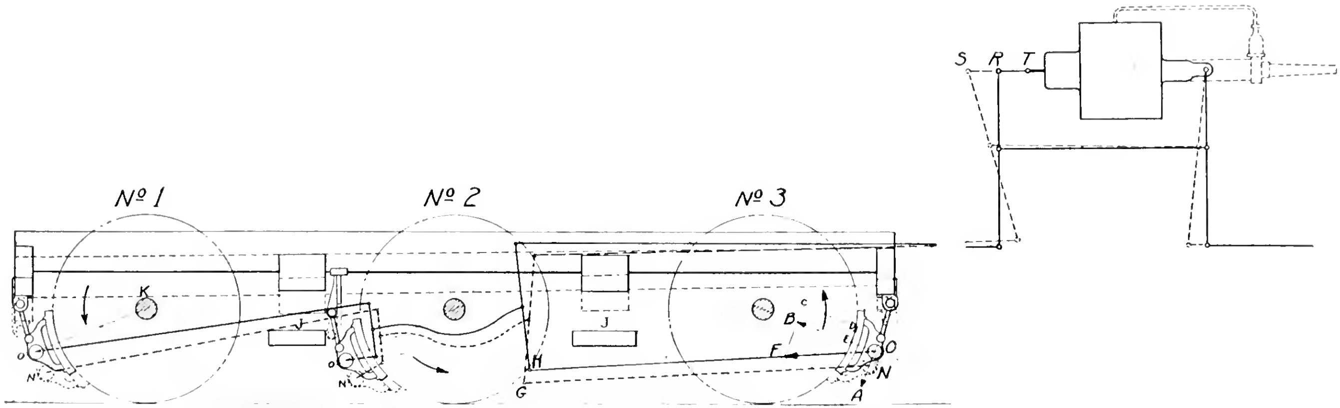
From the foregoing it can be seen that shocks in long trains must be subdued or eliminated if slid flat wheels and the host of other troubles are not to be had.

FOUNDATION BRAKE RIGGING.

No discussion on the matter of train control can in any sense be complete without some reference being made to that part of a brake installation known as the foundation brake rigging. A volume might be written on the subject, but brief mention only will be made here.

As a chain is no stronger than its weakest link, and measures to increase the efficiency of that chain should patently start with that weakest link, so it is also true that the advantages of improved types of air-controlling devices can be realized only in minor degree unless improvements be made in that link; namely, the foundation brake gear, which to-day is the link weakest in efficiency in the whole air brake system. The term "link" takes on

FIG. 10.



Low-hung brake shoes result in the brake hangers pulling the truck frame down about the journal boxes. This permits the shoes to slip still further down on the wheel treads, causing increased or "false" piston travel. The forcing of journals from under their brasses by unbalanced shoe pressures and lack of rigidity in truck construction are also sources of false piston travel.

If for full brake applications (heavy cylinder pressures) the piston travel be correct, which the automatic slack adjuster serves to make it, it will be much *too short* when the light brake pipe reductions are made. To dispense with the slack adjuster would be to risk striking the non-pressure cylinder head with the brake piston and losing the brake to that extent.

Piston travel too short means that the cylinder pressures for these light reductions are much too high; that is, light cylinder pressures are unattainable.

The final result is the *loss of brake flexibility;* the brake must be either "off" entirely or "on" heavier than desired, with rough train handling as the inevitable consequence.

a double meaning when one appreciates the "connecting" rôle of the foundation brake rigging, for it is that mechanical system of levers, rods, pins, hangers, brake beams, brake shoes, etc., which transmits and multiplies the pressure of air in the brake cylinder into brake shoe pressure on the wheels of the car. It is the connection between brake cylinder and wheels which converts fluid pressure at the former point into mechanical force at the latter.

The first and essential requisite of foundation brake rigging is that it be designed with due regard to the strength, rigidity, and arrangement which will always maintain the proper volume proportions between the brake cylinder and auxiliary reservoir; that is to say, it must provide a piston travel constant as nearly as possible under all variations in cylinder pressure. Also, it should not apply to the wheels' unbalanced lateral pressures so great as to force the journal out from under its bearing, causing journal troubles, and to cause excessive binding between journal boxes and pedestal jaws, thereby permitting a shifting of weight from one pair of wheels to another, due to irregularities in the track surface, and causing wheel sliding. Suitable truck design cannot be dissociated from these requirements for adequate brake rigging.

The single-shoe-per-wheel type of foundation rigging in such prevalent use meets none of these requirements, but is a sinner of the first order in its disregard for them. Figs. 10 and 11 illustrate the lack of proper volume proportion maintained by this single-shoe type of rigging. In Fig. 10 the positions of rods, levers, truck frame, and shoes, shown in full lines, are those for the cylinder pressure (about 5 pounds) necessary to just bring the brake shoes against the wheels. The dotted lines show corresponding positions when the cylinder pressure has been built up to some value appreciably higher, such as that for a full service application. The difference in piston travel which this variation in cylinder pressure makes is represented by the distance *RS* on the center line of the cylinder. *This is false piston travel.* The pulling down of the truck frame and other parts from the full line to the dotted line positions is caused by the brake shoes being hung at a point on the wheel considerably below the horizontal center line and being hung from the truck frame, which is separated from the journal boxes and the wheels by the usual truck springs. The braking force being applied along the pull rod *OH* (note the No. 3 pair of wheels for lettering) gives a tangential component *OA* at the brake shoe, which, permitted by the just-

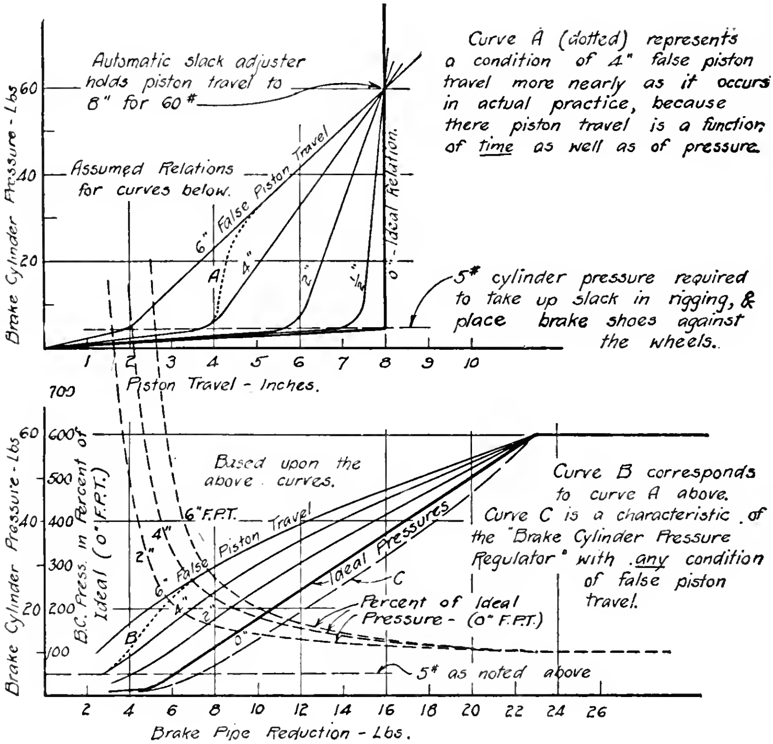
mentioned spring suspension, pulls the shoe down into the dotted position, and this cumulative effect on each wheel results in the false piston travel RS. The operation of the automatic slack adjuster returns point S and, of course, point R towards point T until distance TS equals the setting of the slack adjuster. This reduces distance RT and, therefore, the brake shoe clearance for release position until in many cases RT actually becomes zero. Point T represents the release position of the piston and point R that piston position where the shoes first come against the wheels. That is, there is very much reduced shoe clearance or none whatever with the single-shoe type of brake rigging. And dragging shoes mean highly increased train resistances, with the corresponding reduction in motive power capacity, increase in fuel and water (or electric power) consumption, and shocks due to the necessity for " taking the slack " in order to get a train under way.

The point very difficult for many to grasp, when this action of the automatic slack adjuster is explained, and they immediately suggest dispensing with the adjuster altogether, is that without the adjuster point S might go out so far that the brake piston would strike the non-pressure cylinder head. And this it would do unless careful and repeated manual adjustments were made—adjustments almost impossible to accomplish in the comparatively minor degree required under present conditions. Moreover, such adjustments would merely duplicate in a laborious way the work of the present slack adjuster, and this remedy would provide no betterment whatever. The only " fault " the automatic slack adjuster has is that of revealing the evil of false piston travel and the necessity for striking at the fundamental cause in order to effect a cure. Also, in this same connection, it is well to mention that the slack adjuster should take up about one thirty-second of an inch only for each operation instead of the full distance the piston travels beyond the adjuster setting. Otherwise, where the full overtravel is taken up with one adjuster operation, an unusually high cylinder pressure, such as obtained in emergency, would cause the shoes to grip the wheels, with the air exhausted from the cylinder, to such an extent that the car could not be moved at all.

The distance RT represents the piston travel for light brake pipe reductions, and, as before pointed out, short piston travel

means correspondingly high cylinder pressures and, therefore, severe shocks in long trains, due to serial brake action. Fig. 11 shows what this false piston travel means in the way of giving high cylinder pressures for a light brake pipe reduction at just

FIG. 11.



EFFECT OF FALSE PISTON TRAVEL ON BRAKE CYLINDER PRESSURES FOR VARIOUS BRAKE PIPE REDUCTIONS.

"False" piston travel makes it impossible to obtain light cylinder pressures with the minimum brake pipe reduction required to properly operate the triple valves. This is true if the piston travel be correct for full pressures. Heavy cylinder pressures can always be obtained by increasing the brake pipe reduction. But to have *flexibility* requires that it be possible to apply the brake *lightly* when so desired.

the time when they are not wanted. When high pressures are desired heavier brake pipe reductions can readily be made, *but if flexibility is to be had it is indispensable that the brake installation permit obtaining light cylinder pressures as well as heavy ones.*

(*To be continued*)

THE EFFECTS OF EXPOSURE ON TAR PRODUCTS.*

BY

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It has been shown on several occasions that changes occur in bituminous materials on exposure to the action of air and sun. Such changes are not due merely to the volatilization of lighter oils, as shown in a previous paper [1] upon this subject, but also to chemical changes in certain constituents of the bitumen, such as molecular rearrangements, inter-reactions, and oxidation. Changes of such a nature were demonstrated in the case of native asphalt and petroleum products by abnormal increases in the percentage of bitumen insoluble in paraffin naphtha, and in the case of tars by abnormal increases in the percentage of free carbon.

The present study was instituted for the purpose of extending the work through a greater range of tar products and to determine what relation, if any, existed between the changes brought about by exposure and those produced by laboratory distillations.

Seven samples were chosen, including two refined coal-tars, one refined water-gas tar, one refined mixed tar, two tar-asphalt mixtures, and one crude coke-oven tar. The results of the usual examination made according to methods published in Bulletin 38 [2] of the Office of Public Roads, United States Department of Agriculture, are given in Table No. 1. In addition, a dimethyl-sulphate test as described in United States Department of Agri-

* Communicated by Logan W. Page, Director, Office of Public Roads and Rural Engineering, Washington, D.C.

[1] *Jour. Ind and Eng. Chem.* (1913), vol. 5, No. 1. A paper presented at the Eighth International Congress of Applied Chemistry, New York, September, 1912.

[2] "Methods for the Examination of Bituminous Road Materials."

TABLE I.

Analyses of Samples Used in Exposure Tests.

Material	Refined coal-tar		Refined mixed tar		Crude coke-oven tar		Refined coal-tar		Tar-asphalt mixture		Water-gas tar preparation		Refined water-gas tar	
Sample number	3896		4797		5123		5627		5992		6672		X	
Specific gravity 25°/25° C.	1.215		1.244		1.206		1.256		1.177		1.126		1.184	
Float test at 32° C.	1′ 5″		......		......		......		1′ 30″		......		......	
Float test at 50° C.	......		4′ 29″		......		2′ 16″		42″		......		2′ 21″	
Viscosity Engler, 50 c.c. at 50° C.	......		......		......		......		......		29.8		......	
Bitumen soluble in CS_2	......		82.79		91.16		70.29		85.35		97.40		99.23	
Free carbon	19.36		17.13		8.77		29.65		14.57		2.47		0.72	
Inorganic matter soluble	......		0.08		0.07		0.06		0.08		0.13		0.05	
	......		100.00		100.00		100.00		100.00		100.00		100.00	
Distillation	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight	Per cent. by volume	Per cent. by weight
Water	0.0	0.0	0.0	0.0	1.0	0.8	Not made		Trace	Trace	0.0	0.0	Not made	
First light oils (to 110° C.)	0.2	0.2	0.0	0.0	0.4	0.3			0.3	0.2	0.6	0.5		
Second light oils (110°–170° C.)	3.2	2.5	0.4	0.3	2.0	1.7			0.6	0.4	1.9	1.6		
Heavy oils (170°–270° C.)	29.6	25.1	23.2	18.8	14.0	12.3			18.2	15.6	21.4	18.8		
Heavy oils (270°–315° C.)	.....	.....	.....	.....	7.9	6.9			9.7	8.5	14.5	13.1		
Pitch residue	*67.0	*72.0	*76.4	*80.4	74.7	77.6			71.2	74.6	61.6	65.9		
Total	100.0	99.8	100.0	99.5	100.0	99.6			100.0	99.3	100.0	99.9		

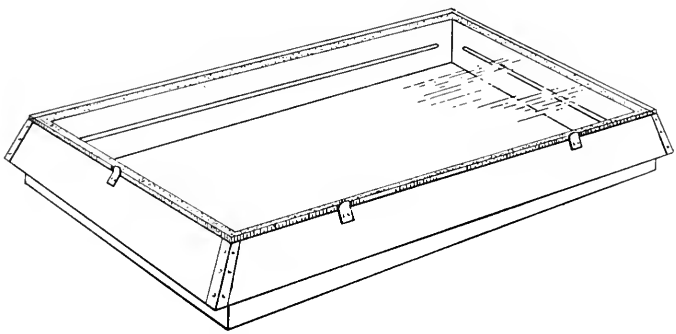
Dimethyl Sulphate Test:	Tar-asphalt mixture	Water-gas tar preparation
Per cent. insoluble (270°–315° C. fraction)	1.25	7.5
Per cent. insoluble (315°–350° C. fraction)	12.5	10.0
Per cent. insoluble (350°–375° C. fraction)	28.5	7.5

* Distillation made by old method (to 270° C.).

culture Bulletin No. 314 [3] was performed on distillates from the two tar-asphalt preparations.

Briefly stated, the method of procedure was as follows: Samples of each material were exposed to the action of sun and air for three months, which the previous investigation seemed to indicate was sufficient to bring about the maximum changes desired. Examinations were made at the end of each succeeding month to determine the change in weight and extent of hardening. In order to compare the effect of exposure with straight distillation, distillations in an Engler flask were made on each sample to produce a residue corresponding, in percentage by weight of the amount taken, to the residue produced on exposure,

FIG. 1.



Box used for exposure tests.

and the consistency of the residues thus produced was determined. Changes in the samples due to volatilization or other causes were noted by estimation of the percentage of material insoluble in carbon disulphide in the various residuums.

The exposures were made in a box of the same type used in previous work, shown in Fig. 1. It was made of 3/4-inch wood and had interior dimensions of 25 by 14 1/2 by 2 inches. This was covered with a plate of 1/4-inch plate glass resting on a strip of thick felt fastened to the sides of the box so as to make a tight joint and exclude all dust. Slots 1/4 inch wide were cut through each side of the box, and to prevent the entrance of rain these were protected by a thin board extending from the rim at

[3] Revision of Bulletin 38.

an angle of about 45 degrees. Cotton batting was packed under this board against the slots to exclude dust from the outside air.

To approximate the constant circulation of air over bituminous materials exposed to actual service conditions, a current of air taken from a pressure pump and passed through a water wash-bottle to remove dust was introduced through a glass tube which passed through one of the slots and terminated at the centre of the box. The tube is shown in Plate I, which represents one-half of the box. This constant current of dust-free air tended also to keep dust from entering the box, and at the end of three months the clean, glossy surface of the harder samples demonstrated that practically no error had been introduced by contamination with dust.

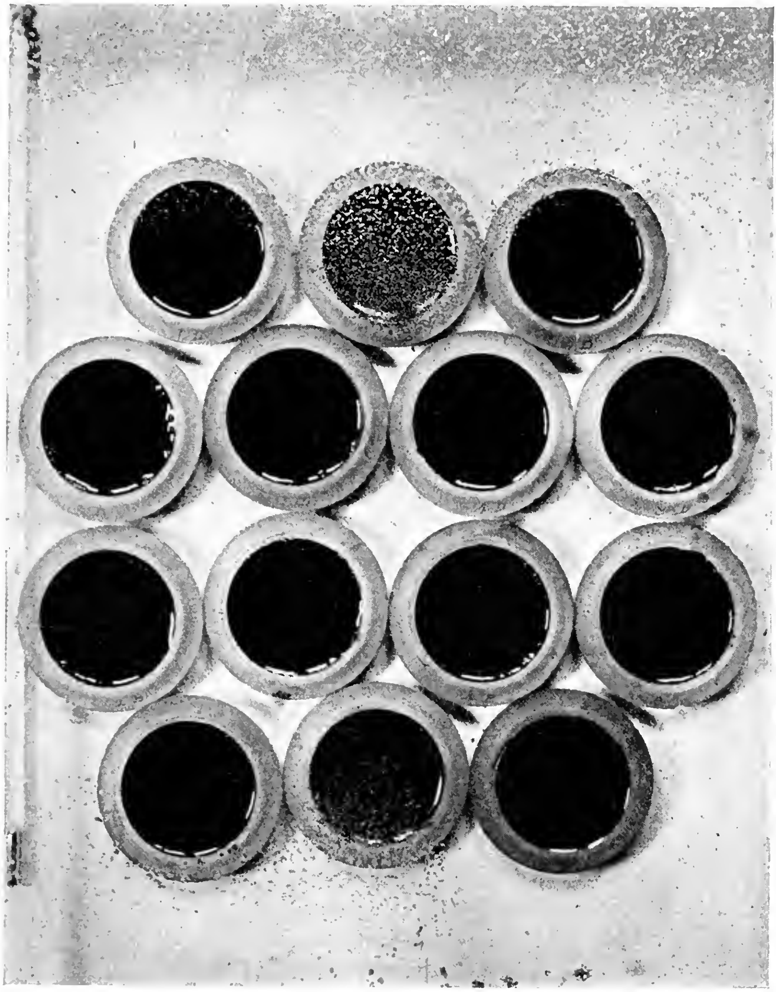
The samples to be exposed were placed in Syracuse watch-glasses having depressions approximately 47 mm. in diameter and 8 mm. deep. Four specimens of each of the seven samples were prepared by accurately weighing 12 gms. of bitumen into a tared watch-glass, thus insuring practically a uniform depth of material for each specimen. The twenty-eight specimens were then symmetrically arranged in the exposure box in four rows, as shown in Plate I, so that the four of each particular sample were equidistant from the centre of the box and the inlet of the air current. A thermometer was placed in the middle and the box set lengthwise on a shelf outside a window having an open southern exposure. The box was exposed in the late afternoon of April 21.

The next morning at 9 o'clock it was noted that brilliant white flaky crystals of naphthalene had formed on the under side of the glass. The temperature recorded in the box at this time was 35° C., but this gradually increased, and the crystals began to melt to a colorless oil. From Plate I, which was photographed at this time, it may be seen that the sublimation is greatest over the specimen numbered 3, which is sample No. 5123, the crude coke-oven tar.

At the expiration of one month's time all the specimens were removed from the box and weighed to determine their loss in weight for each set for this time. Three sets were then replaced in the box for continued exposure in the same position they had previously occupied, while the fourth was subjected to tests to determine its consistency and percentage of free carbon. The

consistency was determined by float tests at 100° C., a temperature which it was felt would be sufficiently high to provide for a

PLATE I.

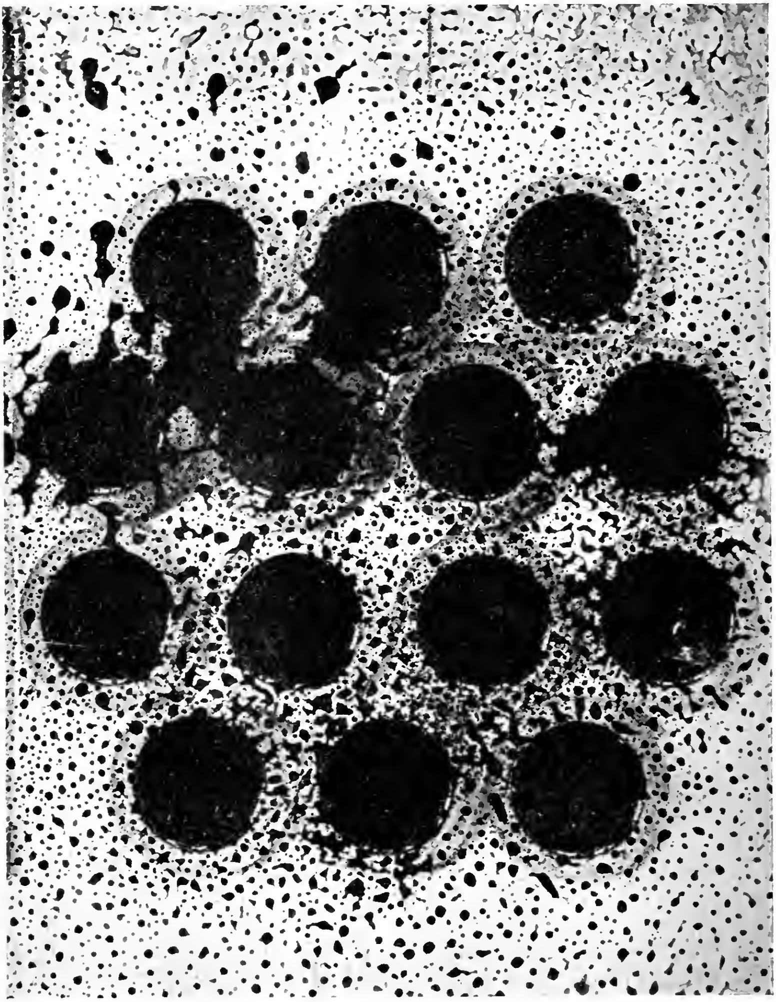


Appearance of exposure box after 24 hours.

satisfactory test on later samples, and also by penetration tests at 25° C., 100 gms., 5 seconds, when the material was sufficiently solid to permit it.

The above procedure was repeated at the expiration of the second and third months. At the end of each month an irregular

Plate II.



Right half of exposure box, showing appearance of hardened, gum-like distillate on under surface of glass.

deposit of a red, gum-like substance, previously noted by Hubbard and Reeve,[4] was found on the under side of the glass cover.

[4] *Loc. cit.*

Plate II shows the appearance of this deposit at the end of the first month. Each time, before the cover was replaced, the gum, which is partially soluble in ethyl alcohol, but almost insoluble in carbon disulphide or benzol, was removed.

During the three months' exposure a current of air was passed through the box during the hours from 9 A.M. to 4:30 P.M.; the rate of flow was measured occasionally and averaged about 0.4 cubic feet per hour, a rate which would displace the atmosphere within the box about once per hour. During the first month readings were taken of the temperature inside the box at 9 A.M., 2 P.M., and 4:30 P.M., and it was found that the average temperatures were as follows: At 9 A.M., 27° C.; at 2 P.M., 57° C.; at 4:30 P.M., 37° C. On heavily clouded days the temperature varied but little during the day, but on days when the sun shone very brightly the temperature advanced rapidly from 9 to 2 o'clock, a maximum rise of 46° C. being recorded, from 25° to 71°. On such days the temperature at 2 o'clock varied from about 68° C. to 79° C. This is, of course, a higher temperature than would obtain in service conditions, and for purposes of study and comparison this work must be considered as possessing the character of an accelerated test.

Table II presents the values obtained by examination of the residues for the three months' exposure, together with corresponding values for the original samples for comparative purposes. In reviewing the table it may be seen that the average loss on a set of samples tested at the end of each period of exposure checks reasonably with the losses on the individual samples for the same period, indicating that the values obtained in testing the residues thus obtained are fairly comparable from month to month. All the samples began to lose weight on exposure, and the loss increased during the entire term of exposure, with the exception of the heavy refined coal-tar, No. 5627, where the residue from the two and three months' exposures is practically the same percentage of the original, and likewise has the same consistency.

Allowing for some experimental errors, it is evident that the organic matter insoluble in carbon disulphide increased gradually even in the case of sample No. 5627, which did not lose in weight appreciably after the second month. Throughout the present discussion this organic matter has been referred to as free

carbon, although it is not unlikely that it may be partially composed of alteration products of tar distillates similar to the gum-like-substance formed on the glass cover of the exposure box.

An error in some of the determinations of free carbon at the end of the first month is particularly noticeable, but unfortunately sufficient material was not available for repeating this work.

Table II.

Tests on Samples Subjected to Exposure.

	Sample number........	3896	4797	5123	5627	5992	6672	X
Time of exposure		Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Original	Float test.........	32° C 1′5″	50° C 4′29″	Fluid	50° C 2′16″	32° C 1′30″ 50° C 42″	Fluid	50° C 2′21″
	Free carbon.......	19.36	17.13	8.77	29.65	14.57	2.47	0.72
1 month	Per cent. loss, average of 4 specimens	10.17	2.27	17.68	7.26	10.76	19.32	3.25
	Per cent. loss, specimen tested.......	10.32	2.39	17.92	7.34	10.76	19.71	3.27
	Float test at 100° C.	24″	41.6″	30.3″	60″	34.1″	33.5″	28″
	Penetration, 25° C..	190	47	82	16	116	111	89
	Free carbon.......	25.21	22.46	14.94	33.18	19.46	8.31	3.06
2 months	Per cent loss, average of 3 specimens	12.08	3.23	19.81	7.87	12.11	22.37	5.87
	Per cent. loss, specimen tested.......	12.12	3.23	19.85	8.09	12.07	22.15	6.21
	Float test at 100° C.	33″	44.8″	37.5″	78.5″	34″	38″	43″
	Penetration, 25° C..	79	31	48	8	51	41	37
	Free carbon.......	23.56	20.06	15.15	32.51	18.73	9.27	4.69
3 months	Per cent. loss, average of 2 specimens	13.47	3.87	21.32	8.08	13.01	24.24	6.97
	Per cent .loss, specimen tested.......	13.39	3.77	21.21	7.85	12.84	24.18	6.67
	Float test at 100° C..	41″	55″	47″	78″	48″	59″	49″
	Penetration, 25° C..	50	28	18	11	47	19	20
	Free carbon.......	23.64	21.40	15.90	33.60	20.68	10.02	6.9

That the increase in percentage of free carbon is not due to loss by volatilization alone is evident from Table III, in which are given actual percentages of free carbon determined and the percentages calculated on a basis of the loss of volatile matter at each period. In every case the calculated percentage is shown to be less than the actual percentage, and it is of interest also to

note that the greatest difference occurs in samples wholly or partly of water-gas tar. The crude coke-oven tar shows a decided variation between calculated and actual percentages, while it may be noted that, in the case of the two refined coal-tars, the variation is comparatively small. From these data it seems logical to conclude that changes resulting in the formation of organic matter insoluble in carbon disulphide take place in tars exposed to the action of air and solar heat, but that this formation is less in the case of coal-tar than in the case of water-gas tar.

TABLE III.

Percentage Free Carbon, Actual and Calculated.

Sample number	Material	Original	Residue one month		Residue two months		Residue three months	
		Actual	Actual	Calculated	Actual	Calculated	Actual	Calculated
3896	Refined coal-tar	19.36	25.21	21.6	23.56	22.0	23.64	22.4
4797	Refined mixed tar	17.13	22.46	17.6	20.06	17.7	21.40	17.8
5123	Crude coke-oven tar	8.77	14.94	10.7	15.15	10.9	15.90	11.1
5627	Refined coal-tar	29.65	33.18	32.0	32.51	32.3	33.60	32.2
5992	Tar-asphalt mixture	14.57	19.46	16.3	18.73	16.6	20.68	16.7
6672	Water-gas tar preparation	2.47	8.31	3.08	9.27	3.18	10.02	3.26
X	Refined water-gas tar	0.72	3.06	0.74	4.69	0.77	6.09	0.77

The second phase of this investigation was the comparison of residues obtained from the above exposure tests with those obtained from distillation of the original samples. To secure comparative data, distillations to 315° C. were made in 250-c.c. Engler flasks, according to the published method [5] now in use in the United States Office of Public Roads and Rural Engineering The temperatures of fractionation are those calculated to be the actual temperatures of the vapors, and are based on thermometer calibrations obtained on substances of known boiling-point; namely, water, naphthalene, and diphenylamine. Table IV gives the distillation data so obtained.

Distillations of the samples were then carried on to secure residues of the same percentage of the original material as was obtained by exposure for three months. The data secured in this work are given in Table V.

[5] U. S. Department of Agriculture Bulletin No. 314, "Methods for the Examination of Bituminous Road Materials," p. 21.

It is of interest to note that, while all samples were exposed to the same conditions of exposure, there is a difference of about 84° C. between the maximum and minimum temperatures to

Table IV.

Distillation of Samples to 315° C.

PERCENTAGES BY WEIGHT OF ORIGINAL SAMPLE.

Sample number	3896	4797	5123	5627	5992	6672	X
Material	Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Per cent. water	Trace	Trace	0.50	Trace	0.0	0.0	0.0
Per cent. to 110° C.	0.0	0.0	0.17	0.23	0.28	0.0	0.0
Per cent. 110°–170° C.	0.15	0.0	0.00	0.00	0.00	0.26	0.0
Per cent. 170°–270° C.	13.65	0.51	14.42	8.09	14.45	11.08	0.67
Per cent. 270°–315° C.	5.74	4.11	2.75	5.23	6.36	11.60	3.20
Per cent. residue above 315° C.	80.11	95.30	80.96	85.76	77.93	76.66	95.95
Total	99.65	99.92	98.80	99.31	99.02	99.60	99.82

Table V.

Distillation of Samples to Obtain Residues Corresponding to Residues from Three Months' Exposure.

PERCENTAGES BY WEIGHT OF ORIGINAL SAMPLE.

Sample number	3896	4797	5123	5627	5992	6672	X
Material	Refined coal-tar	Refined mixed tar	Crude coke-oven tar	Refined coal-tar	Tar-asphalt mixture	Water-gas tar preparation	Refined water-gas tar
Water	Trace	0.0	0.6	Trace	0.0	0.0	0.0
To 110° C.	0.0	0.0	0.18	0.0	0.16	0.0	0.0
110°–170° C.	0.09	0.44	0.00	0.19	0.0	0.09	0.0
170°–x° C.	13.85	1.50	13.95	8.35	13.49	11.08	0.73
270°–xx° C.	.....	2.11	3.27	.....	.....	11.49	3.85
315°–xxx° C.	.....	.....	4.10	.....	.....	2.54	3.04
Residue above xxx° C	55.80	95.18	77.55	91.18	85.53	74.34	92.16
Total	99.74	99.23	99.65	99.72	99.18	99.54	99.78
Value of x	264.4	270	270	269.0	259.7	270	270
Value of xx	.....	312.1	315	.....	.....	315	315
Value of xxx	264.4	312.1	343.6	269.0	259.7	327.2	329.6

which the tars were distilled in order to attain the same amount of residue as that left on exposure. It can also be seen that, with the exception of the coke-oven tar (5123), the materials

consisting in all or part of water-gas tar had to be distilled to relatively much higher temperatures than the coal-tar products in order to obtain the desired amount of residue.

The residues obtained from the distillations described above were subjected to tests corresponding to those run on the residues obtained in the exposure box. The results of these tests, together with the corresponding results for the residues from three months' exposure, are tabulated in Table VI.

TABLE VI.

Tests on Residues from Exposure and Distillation.

Sample number	Material	Residue	Per cent. residue	Float test, 100° C.	Penetration, 25° C.	Per cent. free carbon
		Distillation to 315° C...	80.11	45″	32	25.21
3896	Refined coal-tar..	Distillation to 264.4° C..	85.80	34″	158	23.75
		Exposure 3 months.....	86.61	41″	50	23.64
		Distillation to 315° C...	95.30	53″	24	19.69
4797	Refined mixed tar.	Distillation to 312.1° C..	95.18	49″	37	20.15
		Exposure 3 months.....	96.23	55″	28	21.40
		Distillation to 315° C...	80.96	27″	142	12.94
5123	Crude coke-oven tar	Distillation to 343.6° C..	77.55	38.5″	41	12.93
		Exposure 3 months.....	78.79	47″	18	15.90
		Distillation to 315° C...	85.76	84″	5	35.50
5627	Refined coal-tar...	Distillation to 269.0° C..	91.18	68.5″	17	33.35
		Exposure 3 months.....	92.15	78″	11	33.60
		Distillation to 315° C...	77.93	114″	2	21.11
5992	Tar-asphalt mixture	Distillation to 259.7° C..	85.53	37.5″	55	19.30
		Exposure 3 months.....	87.16	48″	47	20.68
		Distillation to 315° C...	76.66	30″	107	3.80
6672	Water-gas tar preparation	Distillation to 327.2° C..	74.34	43″	68	3.30
		Exposure 3 months.....	75.82	59″	19	10.02
		Distillation to 315° C...	95.95	29″	138	1.29
X	Refined water-gas tar	Distillation to 329.6° C..	92.16	42″	66	2.36
		Exposure 3 months.....	93.33	49″	20	6.09

The comparison of the residue obtained from exposure with that from straight distillation carried to a point where the percentage of residue corresponded approximately to the former leads to the conclusion that the hardening effect of exposure is much more than can be attributed to loss by volatilization alone, and that changes in the inherent nature of bitumen take place when exposed to the prolonged action of air and sun. It is evident that the residues from exposure are harder in every case, as shown by both the penetration test and float test at 100° C., which

is more significant when we observe that the distillations were carried further than intended in all cases, the residues obtained being 0.81 to 1.63 per cent. less than the exposure residues. It is also interesting to compare the consistency of a tar residue obtained by distillation to an arbitrary temperature such as 315° C., with that of a residue obtained by exposure. It will be noted that in three cases (5123, 6672, and X) the penetration of the residue from the distillation is very materially higher than that

TABLE VII.

Percentage Free Carbon, Actual and Calculated.

Sample number	Material	Free carbon original	Residue	Actual	Calculated	Increase, actual	Increase, calculated
			Distillation to 315° C.	25.21	24.2	5.85	4.8
3896	Refined coal-tar	19.36	Distillation to 264.4°C.	23.75	22.6	4.39	3.2
			Exposure 3 months...	23.64	22.4	4.28	3.0
			Distillation to 315° C.	19.69	18.0	2.56	0.9
4797	Refined mixed tar	17.13	Distillation to 312.1°C.	20.15	18.0	3.02	0.9
			Exposure 3 months...	21.40	17.8	4.27	0.7
			Distillation to 315° C.	12.94	10.8	4.17	2.0
5123	Crude coke-oven tar	8.77	Distillation to 343.6°C.	12.93	11.3	4.16	2.5
			Exposure 3 months...	15.90	11.1	7.13	2.3
			Distillation to 315° C.	33.50	34.6	3.85	5.0
5627	Refined coal-tar	29.65	Distillation to 269.0°C.	33.35	32.5	3.70	2.9
			Exposure 3 months...	33.60	32.2	3.95	2.6
			Distillation to 315° C.	21.11	18.7	6.54	4.1
5992	Tar - asphalt mixture	14.57	Distillation to 259.7°C.	19.30	17.0	4.73	2.4
			Exposure 3 months...	20.68	16.7	6.11	2.1
			Distillation to 315° C.	3.80	3.22	1.33	0.75
6672	Water-gas tar	2.47	Distillation to 327.2°C.	3.30	3.32	0.83	0.85
			Exposure 3 months...	10.02	3.26	7.55	0.79
			Distillation to 315° C.	1.29	0.75	0.57	0.03
X	Refined water-gas tar	0.72	Distillation to 329.6°C.	2.36	0.78	1.64	0.06
			Exposure 3 months...	6.09	0.77	5.37	0.05

of the residue from the exposure, while with the other four samples the reverse is true. Consistency tests on a residue from tar which has been distilled to a single arbitrary temperature cannot therefore be looked upon as altogether sound bases for comparison. Comparing the solubilities in carbon bisulphide, we note that the residue from exposure contains a greater percentage of free carbon, except with sample 3896, where the difference is slight; that in the case of the coal-tars, numbers 3896 and 5627, the percentage of free carbon is practically the same; and that

numbers 6672 and X, refined water-gas tars, one containing a small amount of a petroleum product, show the largest difference. Table VII presents the percentages of free carbon as determined and those calculated from the original material on the basis of per cent. of residue.

In Table VII it is shown that the actual percentage of free carbon in all residues except two is greater than can be ascribed to loss of distillate alone, and that in the case of all samples except the refined coal-tars there is a large increase of free carbon over the calculated amount in residues formed from exposure.

CONCLUSIONS.

As previously noted, it is realized that the action of air and sun upon bituminous materials in their pure state, as carried on in this work, is probably very different from what it is when the material is in actual service, but our work as pursued would seem to point to the following conclusions:

1. Upon exposure to service conditions tar products materially harden to a much greater extent than can be attributed to loss of distillate alone.

2. The changes which take place other than loss of distillate are accompanied by formation of organic matter insoluble in carbon bisulphide.

3. Tar products containing water-gas tar appear to change to a greater extent than coal-tars, as indicated by the greater formation of organic matter insoluble in carbon bisulphide.

4. The comparative consistency of pitches obtained from distillations of tars to a single arbitrary temperature do not represent the relative behavior of the tars in service.

Hot Water Supply from Sunshine. ANON. (*Scientific American,* vol. cxv, No. 7, August 12, 1916.)—The hot water used by one-half of the residents of Monrovia, Calif., is heated by the sun; and many other establishments, domestic and otherwise, in other localities along the Pacific Coast are at the present time supplied with sun-heated water. The sun imparts its warmth to water exposed in a coil on the roof or at some other favorable location; and, as the temperature of the water in the coil becomes greater than that of the supply source, a circulation is set up and the warmed water moves along through the coils to a storage tank, from which it is drawn for use.

The sun coil in which the operation of heating the water takes place consists of a shallow box about four inches deep, with a copper bottom; and back and forth through this box is an arrangement of pipes through which the water passes. Copper is selected as it is the best conductor of heat, and the pipes are secured in intimate contact with the copper bottom, being soldered to it so as to secure the greatest efficiency. The box is covered with glass and placed at some point where it will receive the greatest amount of exposure to the sun's rays. The California coast seems to be the ideal place for the sunshine water heater, and most of those in use are to be found on the Pacific slope. But there is no reason why they should not be used in other sections of the country, especially through the South, where the sun is regarded as reasonably reliable in the matter of its daily visits.

Gasoline Switching Locomotive. ANON. (*Railway Age Gazette,* vol. 61, No. 6, August 11, 1916.)—The Erie Railroad has adopted a unique plan for taking care of its business in the vicinity of its Erie Street freight station in the city of Chicago. A gasoline locomotive with a hauling capacity of 500 tons distributes cars brought up the Chicago River on barges to the team and horse tracks for loading and unloading. The engine was built by the Baldwin Locomotive Works and is of the following dimensions: Weight in working order, 44,000 pounds; wheel base (4-wheel coupled), 6 feet 6 inches; length over all, 18 feet 8 inches; number of cylinders, 4; cylinder diameter and stroke, 9 inches by 16 inches; diameter of driving wheels, 42 inches. The engine is equipped with a Kingston carburetor. It has both magneto and battery ignition, two speeds, 3½ and 8 miles per hour, chain drive, the Hele-Show multiple disc type clutches for the main clutch and jaw clutches for the transmission clutch. The capacity of the gasoline tank is 35 gallons. The locomotive is equipped with an electric self-starter, headlight, and the various safety devices prescribed by the Interstate Commerce Commission for switching locomotives, modified to suit the special construction of this engine.

NEW METHOD FOR MEASURING RESISTIVITY OF MOLTEN MATERIALS: RESULTS FOR CERTAIN ALLOYS.*

BY

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AND

R. G. SHERWOOD.

THE first-named writer began an experimental investigation of the electrical conductivity of molten metals and alloys in 1911. The electrical conduction at high temperature of all forms of matter was later considered. The results of these investigations have been described in a series of papers,[1] of which five, relating to metallic conduction, have appeared in the JOURNAL OF THE FRANKLIN INSTITUTE.

To obtain accurate data from which curves may be drawn that give the relation between resistivity and temperature over a wide range of temperatures, it was found necessary to devise entirely new methods of producing the required temperature and, also, entirely new methods for measuring the resistivities of materials when in the molten state. Several different methods were developed and used in measuring the resistivities of metals and alloys.

In the paper by E F. Northrup on the "Resistivity of Copper in Temperature Range 20° C. to 1450° C."[2] the best method which had been devised prior to the date of its publication was

* Communicated by E. F. Northrup.

The method here described is the general method devised by E. F. Northrup, modified in some of its details by R. G. Sherwood, and used by the latter for obtaining the results and all data for curves appearing in this article. E. F. N.

[1] *Trans. of the Amer. Electrochem. Soc.*, vol. xx, 1911; also xxv, 1914. *Metallurgical and Chemical Engineering*, June, 1912; May, 1913; Jan., 1914; Feb., 1914; March, 1914; May, 1914; March, 1915. JOURNAL OF THE FRANKLIN INSTITUTE, Feb., 1913; Jan., 1914; March, 1914; July, 1914; March, 1915; and "High Temperature Investigation and a Study of Metallic Conduction," June, 1915.

[2] *Journal of The Franklin Institute*, Jan., 1914.

fully described. Since that time experiments have been conducted by both writers of the present article with the view of making further improvements in the methods of measurement and of collecting additional data. Thus the method, which we describe here in full, has been reached, as it were, by a process of evolution and is, we believe, sufficiently perfected to meet every requirement of simplicity, speed, and precision. It is entirely a direct-reading and zero-method which yields all results without any calculation whatever. We shall state, therefore, rather categorically, that the details which have been shown by our experience should be observed both in the set-up of the apparatus and in the procedure to follow in taking observations. We do this because nearly every possible modification of apparatus, circuits, and manner of taking readings has been considered, and because we have been led to adopt, for one reason or another, what we here describe as being that which, all things considered, best meets requirements.

COOLING CURVES AND RESISTIVITY CURVES.

Importance has long been attached to a study of certain physical characteristics of the metals and alloys by tracing their heating and cooling curves, especially through changes in state. Melting- and freezing-point determinations are made in this way, and data for equilibrium diagrams have been taken largely from such curves. As will appear, however, from what follows, the same and additional information may be obtained, with nearly equal facility and with greater exactness, by tracing, not the progress of cooling of an element, alloy, or compound but the change in resistivity of the material with change in the temperature when this is slowly raised or lowered. The methods which have been perfected for measuring the resistivity of molten materials have enabled us in certain cases to measure simultaneously the resistivities of two metals, under identical temperature conditions, to a temperature as high as 1680° C. When, however, the temperature much exceeds 1000° C. difficulties are encountered from the formation of new chemical equilibria and the contamination of the sample being measured. Below this temperature difficulties of this character do not arise to any serious extent, and, as will appear later on, it is quite as simple to measure with high precision the resistivity of a molten metal or alloy at a temperature near 1000° C. as it is to measure the same property of mercury at room tempera-

tures. Furthermore, below 1000° C., resistivity curves can be traced with nearly the same facility as cooling curves, and they may be carried through changes of phase to low temperatures where the materials are solid.

It seems to us quite certain that data on electrical resistance or electrical resistivity of a metal, and more especially of an alloy in the solid, solid-liquid, and liquid phases, will yield new and valuable information which cannot be obtained from cooling curves or from any of the other methods now employed to study the physical characteristics of alloys.

Following the description of methods of measurement are given some results, obtained by the methods described, for alloys of tin and bismuth.

REQUIREMENTS TO BE MET.

If measurements of resistivity are to be carried higher than 1100° or 1200° C., a wire-wound furnace is unsuitable, and it becomes necessary to employ the type of furnace [3] which was developed by the first-named writer for this particular class of work. When, however, a study of the alloys is under consideration it is generally unnecessary and it is often impossible (on account of vaporization of a metal) to take observations above a temperature of 1000° C. In this case a vertical-type furnace, made by winding an alundum tube with nichrome wire or ribbon, meets every requirement. In what follows we shall confine ourselves to a consideration of measurements of resistivities which can be made in a furnace of this type.

It is necessary to measure the temperature with precision. This can be done with either a resistance-thermometer or with a thermocouple and, also, by a certain special method which will be briefly considered later. We have found a properly constructed thermocouple (its cold junction being held at 0° C. in a Dewar flask filled with cracked ice), which when read with the aid of a Leeds & Northrup potentiometer, fills every requirement of precision. A thermocouple, furthermore, gives the desired temperature-readings in the simplest and most direct manner, and, furthermore, its calibration is effected with greater ease than the calibration of other devices by checking it against the freezing-points of certain metals.

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[3] "A New High Temperature Furnace," by E. F. Northrup, *Metallurgical and Chemical Engineering*, Jan., 1914.

To obtain the value of the resistivity of a molten material, it is very desirable to employ a device which will give this result by direct insertion of the device into a considerable mass of the molten material, contained in a crucible. We have named the instrument devised for this purpose a "resistometer." Its use has many advantages over the earlier devices and methods employed. Previous to the development of the resistometer a small quantity of the molten material was confined in a specially shaped form moulded from refractory material.[4] There are some objections to these earlier methods; for when a small quantity of molten material is confined in a large mass of refractory material the likelihood of contamination of the molten material by contact with its container is considerable, and moulded forms require considerable skill and labor to construct. The resistometer, on the other hand, with its small mass, when inserted in a large mass of molten material, is little to contaminate it.

The desirability of making the readings of resistivity directly in microhms per cm.$^{-3}$ and by means of a null-method requires the use of a Kelvin double-bridge, which is the best type of low resistance-reading device employed with a null-method.

Alternating current must be used for the measuring current. Our experience has demonstrated that where potential terminals come in contact with a molten metal or alloy a not inconsiderable electromotive force is always developed, and that it rapidly increases in magnitude and irregularity as the temperature increases. Above 500° C. these electromotive forces become so large and erratic that it is exceedingly difficult, and at times impossible, to make accurate measurements, if direct current is used as the measuring current. By substituting alternating current all difficulties arising from parasitic electromotive forces and currents vanish.

An alternating-current galvanometer, or other detector of balance of the bridge, which will be responsive to alternating current only and comparable in sensibility to a good D'Arsonval galvanometer, is required when the measuring current is alternating. An alternating-current galvanometer which possesses new features and fills every requirement was designed especially for this work.

In measuring the resistance of molten materials, connections

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[4] "Resistivity of Copper, etc.," Journal of The Franklin Institute, Jan. 1914 ,see p. 7.

or electrodes must be used which shall serve both for current and potential terminals. Tungsten wire, and in many cases molybdenum wire, has proved entirely satisfactory for this purpose at the temperatures used, because neither tungsten nor molybdenum fuses or appreciably alloys with any molten metal not belonging to the iron group.

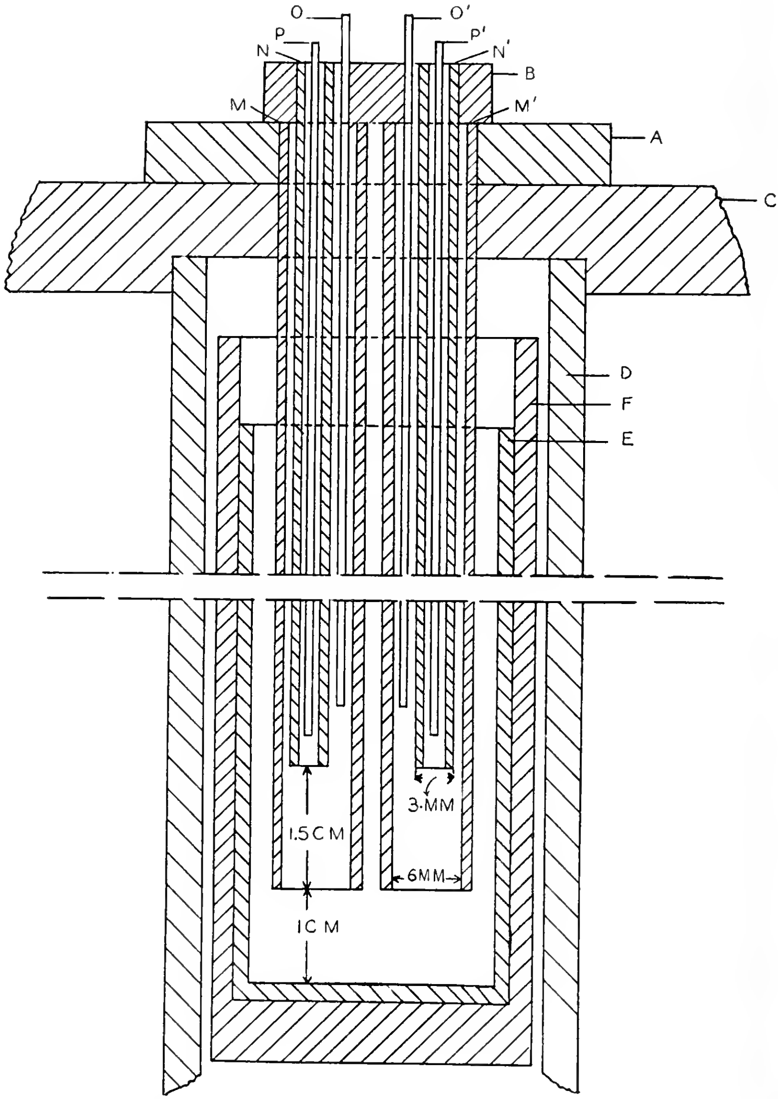
To obtain the results directly in microhms per cm.$^{-3}$ it is necessary to so design the resistometer that its constant may be obtained readily. This is accomplished by inserting it in pure mercury, which serves as a standard of resistivity. When the constant of the resistometer has been obtained thus, the values of the bridge ratio-coils may be then so chosen that the bridge-readings, when multiplied by a power of ten, are in microhms per cm.$^{-3}$. For this reason the ratio-values of two ratio-arms should be adjustable. We proceed to describe in detail the apparatus, and the methods of using it, which have been found to meet the above requirements in all respects.

THE RESISTOMETER TYPE 1.

(*See Fig.* 1.)

Two quartz tubes or Marquardt porcelain tubes MM', having about a 6 mm. bore, are firmly cemented into a small square block of Alberene stone A. A unit is thereby formed which permits the tubes to be lowered into a bath of molten material contained in an alundum crucible E. A second pair of tubes NN' of the same material as MM', having an outside diameter of about 3 mm., are also firmly cemented in a small square block of Alberene stone B, thus forming a second unit. When the latter tubes are in position they are concentric with the tubes MM', as shown in the figure. We shall call the MM' *current-tubes* and the tubes NN' *potential-tubes*. The lower ends of the current-tubes when in position reach to about 1 cm. or more from the bottom of the crucible E. The potential-tubes are of such length that when in position their lower ends are about 1.5 cm. above the ends of the current-tubes. Two tungsten wires, PP', about 1 mm. in diameter, are inserted in the potential-tubes and extend to 1 or 2 mm. from the ends of these tubes. Two other tungsten wires, OO', preferably of a little larger diameter, are inserted in the current-tubes and lie alongside the potential-tubes. The lower ends of these wires should be 0.5 cm. or more above the ends of the potential-tubes. These latter

FIG. 1.



wires constitute the current-leads and the former the potential-leads.

The sample contained in the crucible E should be sufficient in quantity to reach a little above the lower ends of the current-

terminals. Molybdenum may in many cases be substituted for tungsten for the current- and potential-leads. Tungsten is, however, to be preferred if the temperature is to be carried very high. In one experiment a No. 20 tungsten wire and a No. 20 molybdenum wire were placed in molten tin held at 1200° C. for about fourteen hours. The molybdenum wire had dissolved to an extent that reduced it in size to No. 23 B. and S., while the tungsten wire had not perceptibly changed in diameter. Little action is to be expected on either tungsten or molybdenum immersed in any metal or alloy which is molten and under 1000° C.

As shown in Fig. 1, the crucible *E* is placed in a container, *F*, made of Acheson graphite. The main object in using the graphite container is to obtain a reducing atmosphere in the furnace, and incidentally, also, to more uniformly distribute the heat about the crucible *E*. When the chamber of the furnace is filled with a reducing atmosphere the surface of metals which readily oxidize in an oxidizing atmosphere is maintained free from oxide and bright. It is specially important to maintain a reducing atmosphere when working with copper, as this metal dissolves the oxide which forms on its surface and so changes in specific resistance.

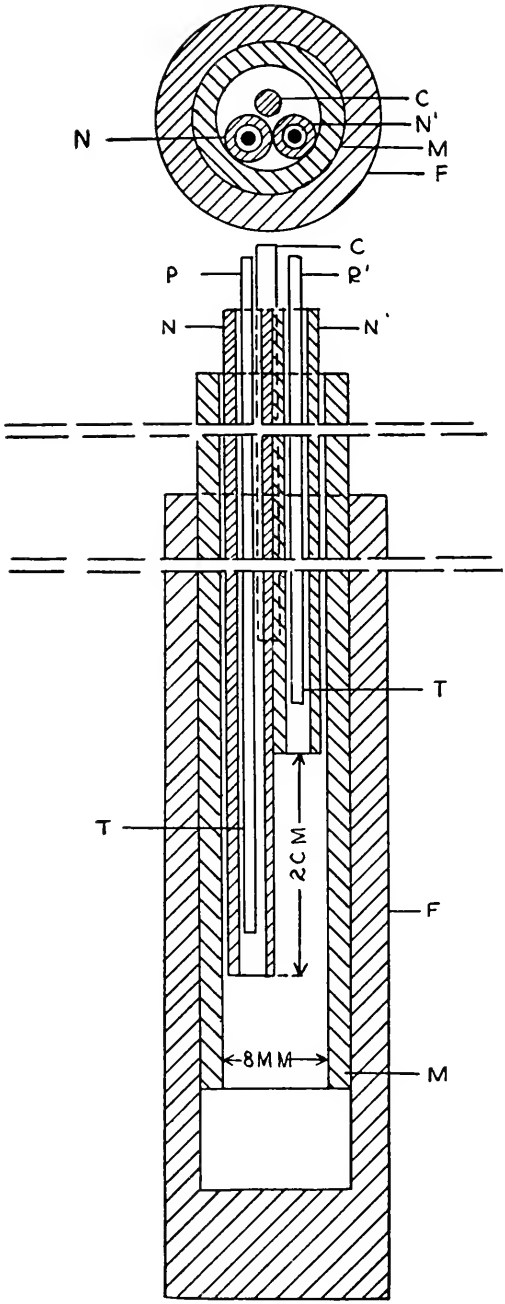
The heater-unit consists of an alundum tube *D* wound with nichrome wire or ribbon. This wire or ribbon winding may with advantage be covered over with alundum cement or "Vulcan paste," which helps to hold the winding securely in position on the alundum cylinder on which it is wound. The alundum cylinder is firmly cemented in a heavy slab, *C*, of Alberene stone. This slab, which may be round or square, also forms the top of any metal or other gas-tight vessel chosen to contain the heater-unit. When working at temperatures under about 500° C. it is convenient to have only air insulation around the heater-unit in order to secure rapid cooling when the current is turned off. When slow cooling is desired this is readily secured by maintaining a reduced heating current, adjusted with a control resistance, through the heater-unit.

THE RESISTOMETER TYPE 2.

(*See Fig.* 2)

In many cases and for certain kinds of work it is desirable to construct the resistometer in another form, employing, however, the same principle as that used in type 1, and using it in the same circuits and in the same manner when measurements of resistivity

FIG. 2.



are made. In this form a single tube, M, only is used, which has approximately the same dimensions and is made of the same material as either one of the tubes of type 1.

Two potential-tubes, NN', firmly cemented together with Vulcan paste, are arranged so that they will readily enter this outside single tube. One of these potential-tubes is longer than the other by 1.5 cm. to 2 cm. When the potential-tubes are in position the lower end of the longer one may reach within a few millimetres from the bottom of the outside tube, *M*, which we designate the *current-tube*. This latter is inserted in a tube, F, of Acheson graphite closed at the bottom. The current-tube may reach a short distance from, or quite to, the closed bottom of the graphite-tube *F*. The sample the resistivity of which is to be measured is poured while molten into the graphite-tube and the current-tube is then inserted, the molten material filling the interior of the current-tube to a level chosen a short distance above the lower end of the shorter potential-tube N'.

One current-lead *C* of tungsten or molybdenum is placed alongside the potential-tubes, its lower end being maintained a little above the lower end of the shorter potential-tube. The graphite-tube or casing forms the second current-lead.

When current is passed through the resistometer there is a drop in potential between the lower end of the shorter and the lower end of the longer potential-tube. There is inserted in each of the potential-tubes a tungsten wire, *T*, which reaches to within a millimetre or two from the lower end of each of these tubes. These potential-leads serve as a means for measuring this potential drop. If the two potential-tubes are firmly cemented together, then the distance between their ends,—that is, the distance between potential-points,—is fixed, and if the two potential-tubes occupy the same position in the current-tube at the time the constant of the resistometer is obtained by measuring its resistance when filled with pure mercury as when measuring its resistance when filled with the molten metal, the resistivity of this latter is to the resistivity of pure mercury as the measured resistance of the latter is to the measured resistance of the mercury. In other words, the cross-section and length of the fluid-column of which the resistance is measured is invariant, because the very slight expansion with temperature of the Marquardt porcelain or quartz of which the current- and potential-tubes are made is quite negligible.

If the lower potential-terminal ends 3 or 4 mm. above the end of the current-tube it is immaterial whether the current-tube reaches to the bottom of the graphite casing or not. All parts of this type of resistometer, current-tube, potential-tubes, tungsten wire potential-leads, and current-lead should be aranged so as to be readily assembled and taken apart because, after the resistometer has been filled with pure mercury for obtaining its constant, it must be freed from the last traces of mercury, which tend to cling to the potential-tubes, before filling it with molten metal or alloy.

The advantages of this single-tube type of resistometer consist largely in its simplicity and compactness and in the fact that it is better adapted than the former type to the measurement of the resistivity of a precious metal or an alloy of precious metals, where, for reason of cost, it is desirable to use small quantities of metal. Again, this type of resistometer when filled with pure molten tin can be used as a pyrometer which will measure temperatures up to 1600° or 1700° C. As has already been shown by the first writer in a previous paper,[5] tin increases linearly in resistance from its melting-point (232° C.) to at least 1680° C., and hence can be used in a resistometer as a pyrometric substance. A measurement of the resistance of the tin contained in the resistometer need only be made at two known temperatures to obtain the calibration of the resistometer, used as a pyrometer up to a temperature of at least 1680° C.

On the other hand, this second type of resistometer is less desirable than the first when one has in view the tracing of the resistivity curves of base metals or their alloys. The first type can be made more robust and is more easily cleaned, as it must be when used with different samples, and the vertical distance of the liquid column the resistance of which is measured can be made less than in the second type, a circumstance which insures greater uniformity of temperature in the mass of metal being measured.

In either type of resistometer it is important that the thermocouple should have its hot junction in as close proximity as possible to the column or columns of molten metal contained between the potential-points when the resistance is being measured. In using resistometer type 1, the thermocouple can be immersed with

[5] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1915, p. 625.

the resistometer in the same bath of molten material, and by placing it alongside of and between the two current-tubes the temperature of the columns of material being measured is given with great exactness. When resistometer type 2 is used, it is desirable to submerge the graphite-casing of this, and the thermocouple in close contact with it, in a bath of molten tin. By so doing the temperature will be sensibly the same at the end of the thermocouple and in the interior of the resistometer. We recommend for most classes of work type 1 in preference to type 2.

ALTERNATING-CURRENT GALVANOMETER.

As previously stated the large electromotive forces of a parasitic character which are developed in the resistometer, when this is immersed in a molten metal or alloy, preclude the use of direct current for the measuring current and, therefore, a direct-current galvanometer. We have worked with both 60-cycle and 25-cycle alternating current. The latter is to be preferred, as it is then of less importance, when high precision is required, that the ratio-coils in the Kelvin double-bridge should be free from capacity or inductance. The alternating-current galvanometer which has been designed, two of which were constructed for this work in the shop of the Palmer Physical Laboratory, has proved a very great success and completely fulfils the following requirements for a satisfactory instrument:

The sensibility of the instrument should be fully equal to the sensibility of a good D'Arsonval galvanometer of the type of a Leeds & Northrup "High Sensibility Narrow-coil Galvanometer," known as catalogue No. 2294 and described in the Leeds & Northrup catalogue No. 20. In fact, it was aimed to give the alternating-current galvanometer the same characteristics in performance as this direct-current instrument. The sensibility, however, of the alternating-current galvanometer is not a constant quantity as with a direct-current instrument, but may be varied to any degree within wide limits by simply changing the value of the alternating-current passed through its magnetizing coils. As the damping of the system varies with the square of the field-strength, this latter is chosen of such value, by adjusting the current through the magnetizing coils, that the system after deflection returns aperiodically to zero with the particular resistance in circuit with the swinging coil which is in use. With an adjustment of field-

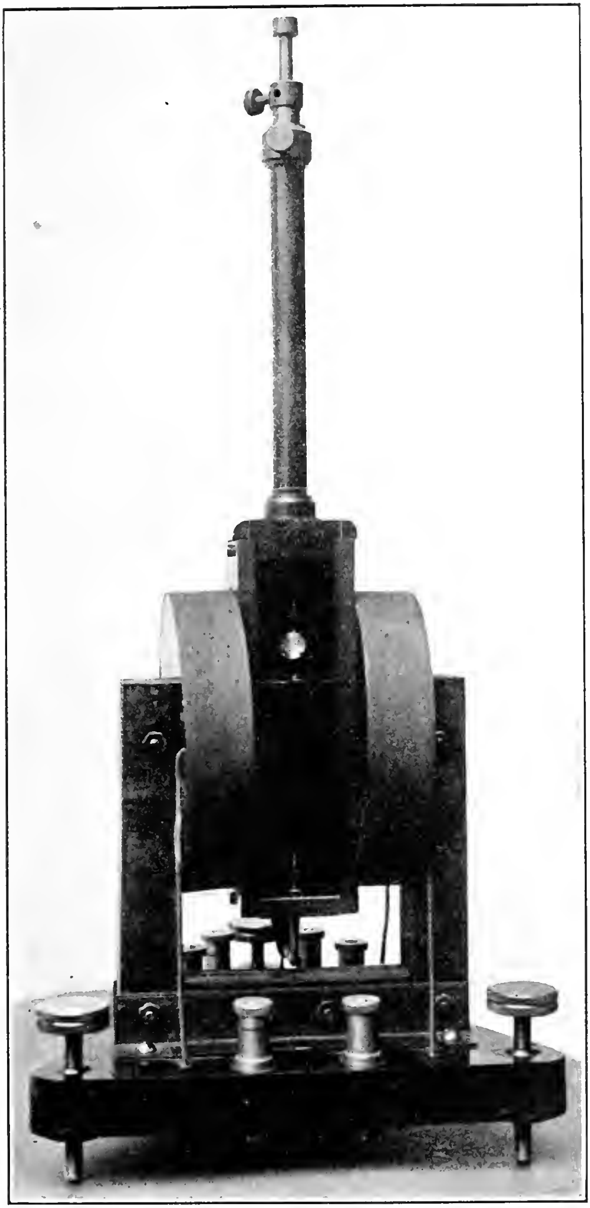
strength made thus, the sensibility of the galvanometer should equal that of the direct-current instrument referred to. The aperiodic time of swing of the galvanometer should not exceed two or three seconds, and this requirement makes it necessary to use a narrow, light coil for the swinging system. In fact, the swinging system used was identical with that used in the Leeds & Northrup galvanometer just referred to.

When the alternating-current galvanometer is in use the swinging system is necessarily on closed circuit, and, as this latter hangs in a field in which the magnetic flux is alternating, currents are induced in the swinging-coil circuit. It is essential that these induced currents should not cause the system to seek a position of stable equilibrium other than that at which it comes to rest when no currents are flowing. This requirement has been fully met by the special shape which has been given the pole-pieces of the laminated galvanometer-magnet. It has never been found necessary to make any phase adjustments of any of the currents.

The magnetizing coils, two in number, may be joined in series or parallel combination. They are always connected *in series* with the main circuit of the Kelvin double-bridge, and hence must be able to carry without heating and without too strongly magnetizing the magnet, a current which is at least as large as the current passed through the bridge. It is unadvisable to cut down the current through the magnetizing coils, which are highly inductive, by means of a shunt. The bridge, however, being non-inductive, may be shunted to any extent. Hence it follows that the current through the magnetizing coils required to energize the field-magnet may be chosen much larger than, but never less than, the current which is passed through the bridge.

The general appearance of the galvanometer is given in Fig. 3, reproduced from a photograph, while Fig. 4 shows a few details of construction. In referring to Fig. 4 it will be noted that the fixed iron core-piece between the pole-faces, which is generally used with direct-current instruments, is omitted. The pole-faces are hollowed out so that the coil swings in a hollow cylinder. This construction is used for the reason that when the coil is on short circuit it will tend to set itself in the weakest part of the field. The shape which has been given the pole-pieces makes the position of stable equilibrium for the system that which corresponds to zero reading on the scale.

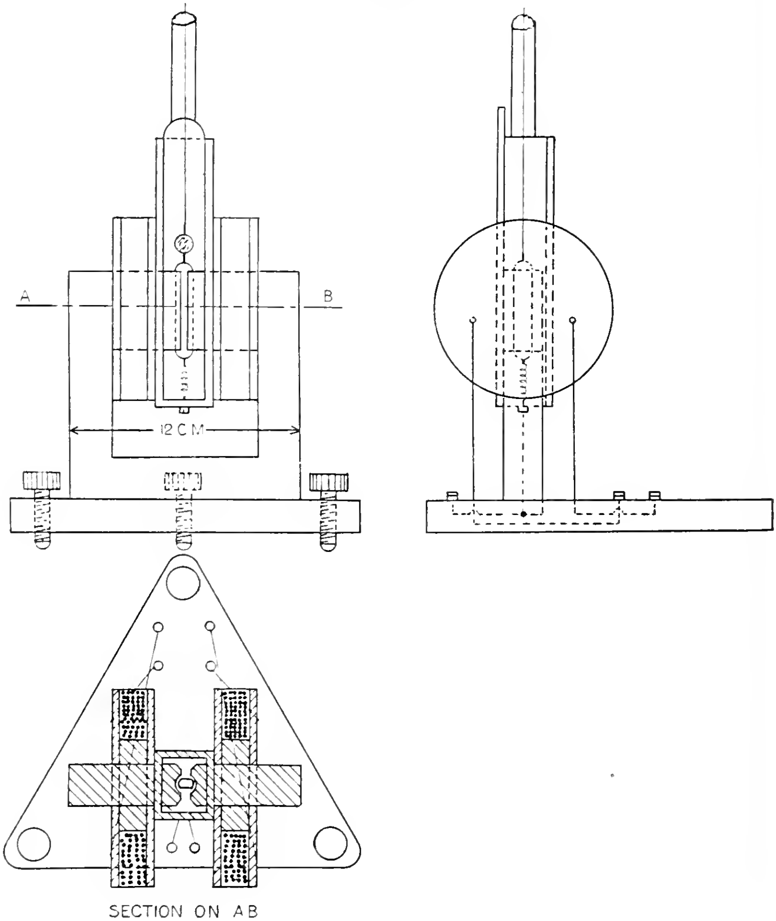
FIG. 3.



Alternating Current Galvanometer

The system hangs in a box of hard rubber with a glass front which exposes it to view. All metal parts in the neighborhood of the system are avoided to prevent the formation of eddy currents.

FIG. 4.



When adjustments are properly made the performance of this instrument with current of 25 cycles or 60 cycles is in all respects like that of a quick-acting, aperiodic, highly-sensitive direct-current instrument.

THE KELVIN DOUBLE-BRIDGE.

It is very much more convenient for work of this class to employ a type of Kelvin double-bridge in which a balance is obtained by varying the position of the potential-points on a low-resistance standard than one in which a balance is obtained by varying the ratio-coils and using a fixed low-resistance standard. The type of variable low-resistance standard used in all our work is the one made by Leeds & Northrup known as catalogue No. 4300 and described in catalogue No. 40, p. 7 *et seq.** The variable ratios were obtained with an Otto Wolff box, designed for use with low-resistance fixed standards for measuring low resistances. The fixed ratio-coils were obtained with single-resistance units.

CIRCUIT-CONNECTIONS, USING RESISTOMETER TYPE 1 AND A THERMOCOUPLE.

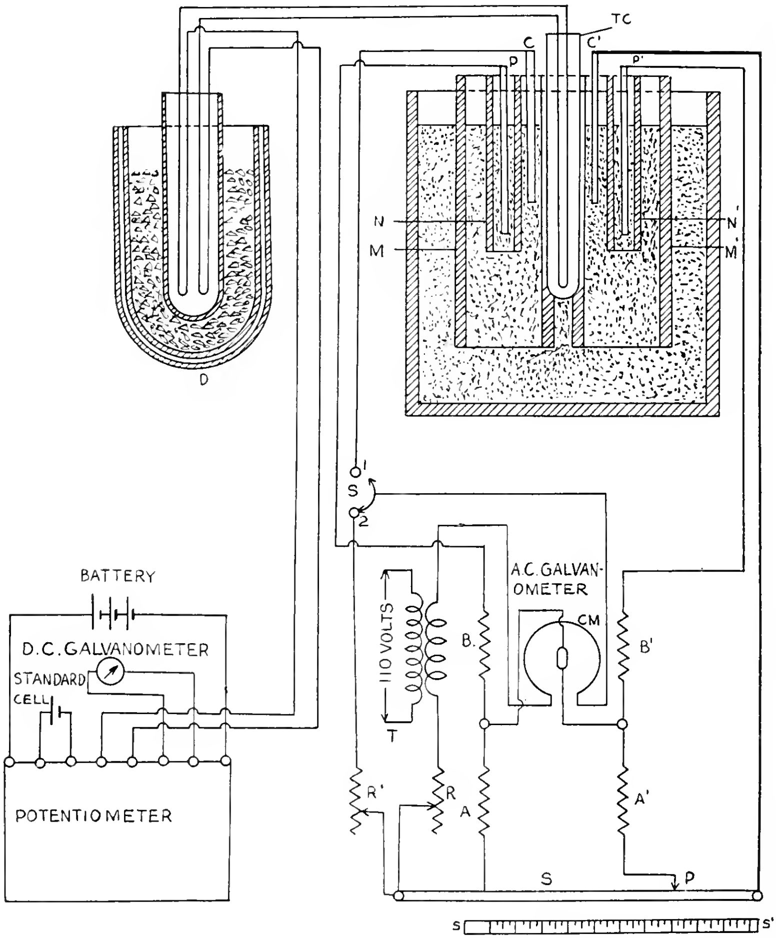
(See Fig. 5.)

The electrical circuits employed and the manner of including the resistometer type 1 in these circuits are shown diagrammatically in Fig. 5. The resistometer itself is shown with its lateral dimensions greatly exaggerated for the sake of clearness. The source of current is the secondary of a step-down transformer T. S is a switch which when in position 2 cuts the resistometer and Kelvin double-bridge out of circuit and puts the magnetizing coils, CM, of the galvanometer in circuit with the transformer-secondary and the two resistances, R' and R. When the switch S is in position 1 the resistance R' is cut out of circuit and the resistometer and Kelvin double-bridge are thrown into circuit with the source of current. The switch S is so constructed that neither contact 1 or 2 is broken before the other is made. This is necessary to prevent a sudden small deflection of the galvanometer which would result if the current through its magnetizing coils were momentarily stopped. The resistance R' is given such a value that the total resistance in circuit with the secondary of the transformer is the same whether the switch S is in position 1 or in position 2. The object in being able by means of the switch S to throw the bridge and resistometer out of circuit is, that by so doing the zero position of the galvanometer may be located. Re-

* For full treatment of the theory and use of the Kelvin double-bridge, see Northrup, "Methods of Measuring Electrical Resistance," McGraw-Hill Book Co., 1912. *Arts.*, 609–612.

sistances A and A' are fixed ratio-coils, generally chosen 1000 ohms each. Resistances B and B' are ratio-coils which can be varied. They are chosen of such a value that the settings of the slider P, as read on the scales S, S' shall indicate the resistivity of

FIG. 5.



the sample, when multiplied by some power of ten, in microhms per cm.$^{-3}$. In our work we used the set of Otto Wolff ratio-coils above referred to for obtaining the required resistance values of B and B'. The method of finding the proper values for B and B', to make the bridge read directly resistivity in microhms will be explained later.

The thermocouple, TC, is located in the bath of molten material so that its hot junction is midway between the bottom ends of the two potential-tubes, N N' and the two current-tubes M M'. Its cold junction is located in the Dewar flask D, filled with cracked ice, and the terminals of copper wire which lead from the cold junction are joined to the potentiometer as shown in Fig. 5. Our work was all done with a Leeds & Northrup potentiometer, catalogue No. 7551, described in catalogue No. 70.

CIRCUIT-CONNECTIONS, USING RESISTOMETER TYPE 2 AND A TIN-PYROMETER.

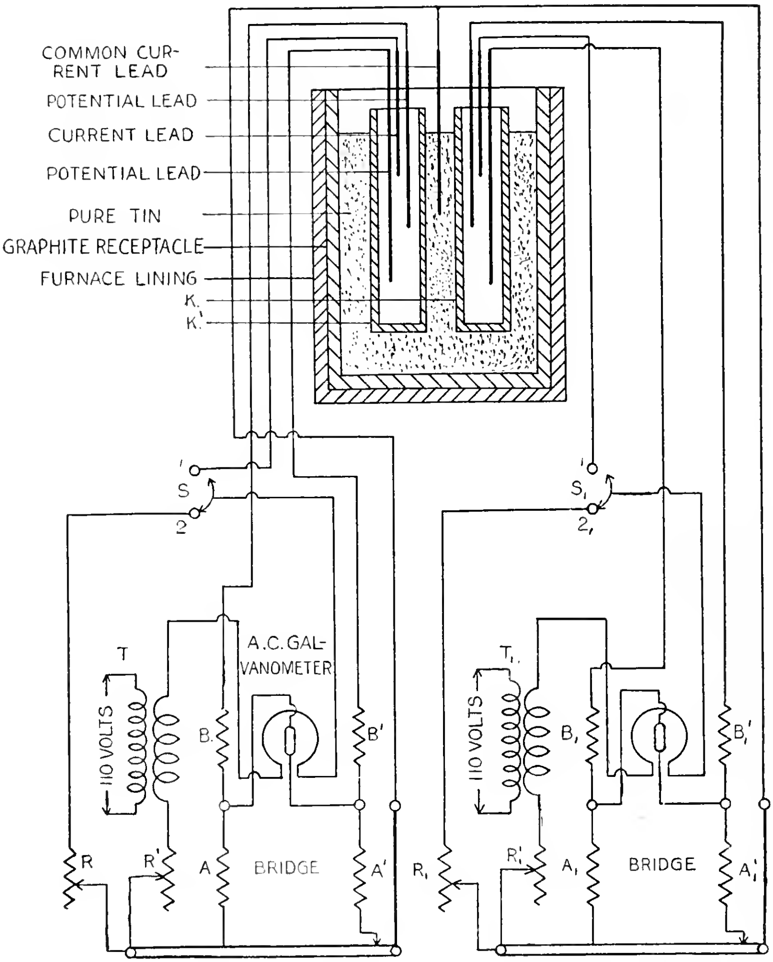
When using resistometer, type 2, it is convenient, if one is supplied with two alternating-current galvanometers and two Kelvin double-bridges, to also measure the temperature with a resistometer, type 2, filled with pure tin. In this case the two resistometers, one of which becomes a pyrometer, are both inserted in a bath of molten tin, as indicated at K and K', Fig. 6. It is possible to so choose the resistances of the Kelvin double-bridge, used with the resistometer filled with pure tin and now called a pyrometer, that the bridge-readings are directly in degrees C., and also to so choose the values of the ratio-coils connected to the resistometer used for determining resistivity that bridge-readings in this case are in microhms per cm.$^{-3}$. We shall omit explaining these adjustments in detail, but give the circuit connections in Fig. 6.

An extremely important line of high-temperature investigation is an inquiry into the linear increase in resistance of pure metals when carried to a very high temperature. By simultaneously tracing the increase in resistance of two different metals when subjected to identical temperature-conditions, it is possible to ascertain, by studying different pairs of metals taken in different combinations, whether or not they all increase in resistance linearly. The method and connections shown in Fig. 6 are well adapted to this study. By a somewhat similar arrangement the first-named writer has investigated the pair of metals tin and copper[6] and has found that both these metals when in the molten state increase linearly in resistance to at least 1680° C. The second-named writer made this comparison also between the metals lead and tin by using the apparatus and method shown in Fig. 6 and found,

[6] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1915, p. 635.

likewise, that both tin and lead increased linearly in resistance when molten up to about 1575° C. We believe that the method devised, as shown in Fig. 6, is most convenient for direct comparison to a very high temperature of the rate of increase in resistance

FIG. 6.

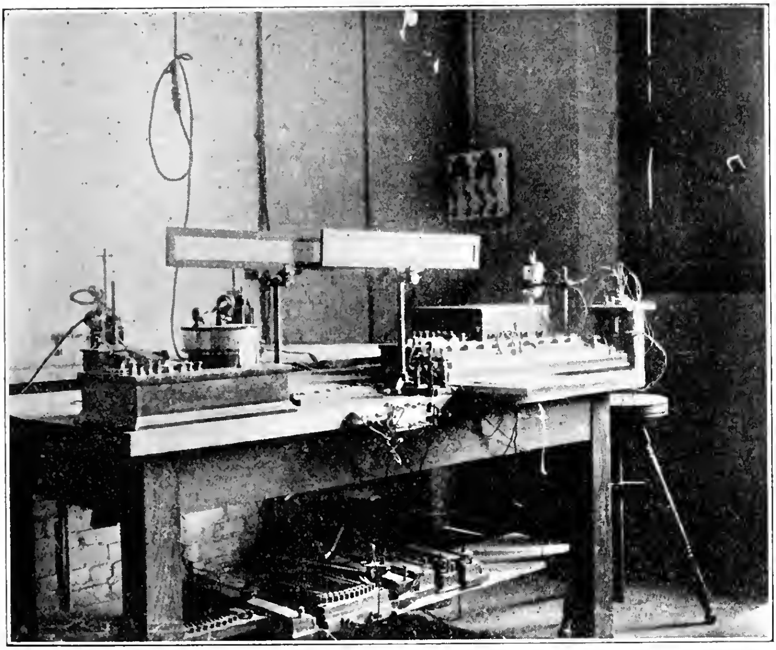


of two molten metals or alloys. If this comparison were to be made of various pairs of metals chosen in different combinations *it would firmly establish an extension, to a high temperature, of the temperature-scale on a basis new and quite as reproducible as the gas-scale.*

CALIBRATION OF RESISTOMETER; ADJUSTMENT OF RATIOS.

The theory of the method of adjusting the ratio-coils in a Kelvin double-bridge so that the readings on the variable low-resistance standard when multiplied by a power of ten will be in microhms per $cm.^{-3}$ has been given by the first-named writer in a former paper.[7] The calibration of the resistometer and the adjustment of the ratio-coils, however, may be determined experi-

FIG. 7.



Assembled apparatus used in measurements

mentally and simultaneously without any calculation, in the simplest manner possible, as follows:

A container of the same dimensions as the one destined to contain the sample is filled with pure mercury. The resistometer is placed in this mercury, the temperature of which is accurately taken with a mercury thermometer. The two ratio-coils A A' (Fig. 5) are given some arbitrary value, say 1000 ohms. A set-

[7] "Resistivity of Copper in Temperature Range 20° C. to 1450°," JOURNAL OF THE FRANKLIN INSTITUTE, Jan., 1914, pp. 9–11.

ting is then made on the variable low-resistance standard which when multiplied by some power of ten is equal to the specific resistance of the mercury in ohms when at the temperature recorded. A balance of the bridge is then effected by the simultaneous adjustment of the ratio-coils *B B′*. The readings of the bridge when multiplied by the proper power of ten will now give the resistivity of the mercury in microhms per cm.$^{-3}$. Likewise, if a molten metal of unknown resistivity be substituted for the mercury and the bridge be again balanced by changing the setting on the variable low-resistance standard the new setting, when multiplied by the same proper power of ten, is the resistivity of the molten metal. For example: if the mercury has the temperature of 25° C. its resistivity is 96.268 microhms per cm.^{3} Choosing the ratio-coils *A A′*, 1000 ohms, and setting the variable resistance at 0.009628 ohm, the bridge is balanced by adjusting the ratio-coils *B B′*. It is evident that the bridge-reading when multiplied by 10^4 is the resistivity in microhms of mercury at 25° C., and it is obvious that, the ratio-coils being left unchanged, all bridge-readings henceforth, whatever sample is chosen, will give the resistivity of this in microhms per cm.$^{-3}$.

By making these adjustments the resistivities of the samples studied are determined without any calculation whatever, and the result is that it is actually simpler to measure the resistivity of molten brass, for example, at 800° C. than to determine the resistivity of a rod of metal at room temperature. When the resistometer-tubes are made of Marquardt porcelain the temperature, given a suitable furnace, can be carried to 1600° or 1700° C., and it follows that, when one is supplied with the equipment which has been described, the resistivities of molten metals can be determined with the greatest ease, simplicity, and accuracy to even this high temperature.

MANIPULATION.

Before beginning a series of observations a test should be made of the measuring apparatus to ascertain if any defects exist in the circuits, such as incorrect connections, bad contacts, poor insulation, etc. For making this test the ratio-values of the bridge are set close to the values which are to be used in the measurements, and the same current- and potential-leads, which attach to the resistometer, are connected to a low-resistance standard of

manganin. A standard should be selected which has a resistance not far from the average resistance of the resistometer. The resistance of this manganin standard is then measured, a balance being obtained by varying the setting on the low-resistance standard. If a correct resistance value is now obtained for the manganin standard-resistance, one is assured that the bridge and measuring circuits will yield correct results when used to measure the unknown resistance of the resistometer. In fact, by this procedure the determination of the unknown resistance is reduced, almost, to a substitution method of measurement, and the chance of introducing a systematic error into the resistance-measurements becomes practically nil.

There is one important precaution which requires consideration, if high precision is desired. This consists in so selecting the values of the ratio-coils A A' that when the resistance values of the ratio-coils B B' are correctly chosen in the manner previously described, these latter values will be very large in comparison with the resistance of the tungsten or molybdenum potential-leads. The reason for this depends upon the fact that, so much of these leads as are in the lower end of the resistometer, change in resistance when the temperature of the resistometer is changed. By making the resistances of B B' very large in comparison with this variable resistance of the potential-leads, the per cent. variation in the ratios B/A and B'/A' may be made quite negligible under all variations in temperature.

It is not improbable that on first heating a sample in a crucible some contaminating material may be dissolved out of the substance of the crucible and so affect the resistivity of the sample. To guard against this possibility it is well to first heat in the crucible to be used some of the sample material, carrying the temperature higher than one intends to carry it in making measurements. This first lot of sample material is then replaced by a fresh lot, when it may be safely assumed that the first lot of material has taken up all contamination from the crucible and that the second lot will not take up any contamination, and hence may be used for the sample to be measured. After a test on a sample has been completed it becomes necessary to thoroughly free the resistometer from all traces of the material tested before it can be used for testing another sample of a different kind. If the sample tested has a melting-point lower than the boiling-point of mercury

and is soluble in mercury, the resistometer may be easily cleaned by immersing it in hot mercury until all traces of the sample tested are dissolved off the tubes and metal terminals. Any mercury which clings to the parts of the apparatus is easily wiped off with a cloth. If the material to be removed has a higher melting-point than boiling mercury or does not readily dissolve in mercury, it may still be removed by first immersing the resistometer in molten tin, carried to the necessary temperature to dissolve the material to be removed, and then later remove with hot mercury the tin which remains.

Either type of resistometer may be used as a pyrometer for temperatures up to 1600 to 1700° C. Type 2, however, is better adapted to this service. It is very advantageous to so calibrate and employ it that the readings on the variable low-resistance standard of the Kelvin double-bridge will be (with the subtraction of a single constant) in degrees of temperature.

The following affords a simple and wholly satisfactory method of calibrating the resistometer and evaluating the constants:

Assume that a metal is selected for the pyrometric substance which is molten over the range of temperature to be measured, and that the resistance of this metal, when molten, is a linear function of the temperature. Then calling R_t the resistance at temperature t and R_o the resistance at 0° C. of this metal between potential-points of the resistometer, we can write,

$$R_t = mt + R_o \quad \text{(1)}$$

where m is a constant and t is the temperature.

By the law of the Kelvin double-bridge,

$$R_t = \frac{b}{a} S \quad \text{(2)}$$

where S is the reading of the bridge on the variable low-resistance standard and b/a is the ratio-setting used. Then from Equations (1) and (2)

$$\frac{b}{a} S = mt + R_o$$

from which

$$t = \frac{b}{ma} S - \frac{R_o}{m} \quad \text{(3)}$$

The value of the resistance a may be chosen arbitrarily and the

values of m and R_o may be obtained by experiment, in the manner presently to be described, and $\frac{R_o}{m}$ will equal some constant K. When, therefore, m, a, and K are known, the resistance b can be given a value such that $\frac{b}{ma} = 10$, where 10^x is any desired power of 10. When this particular value is assigned to b, Equation (3) becomes

$$t = S\,10^x - K \quad (4)$$

Equation (4) states that the temperature will be given directly in degrees when the reading of the variable low-resistance standard is multiplied by some power of 10 and a constant quantity subtracted from the result. The power of 10 to use will depend upon the resistance-range of the variable low-resistance standard employed. The multiplier of S is 10^5 if the resistance-range of the standard is from 0 to 0.01 ohm. To evaluate the constants m and R_o in Equation (1) it is, of course, only necessary to obtain experimentally the resistance of the resistometer at any two known temperatures where the metal, used as a pyrometric substance, is molten. Thus according to Equation (1) we have for a temperature t

$$R = mt + R_o \quad (5)$$

and for temperature t_1

$$R_1 = mt_1 + R_o \quad (6)$$

From Equations (5) and (6) we easily derive

$$m = \frac{R - R_1}{t - t_1},$$

$$R_o = \frac{R_1 t - R t_1}{t - t_1} \quad \text{and}$$

$$\frac{R_o}{m} = \frac{R_1 t - R t_1}{R - R_1} = K, \text{ a constant.}$$

The best method of obtaining the two resistance-values of the pyrometer R and R_1 at the two temperatures t and t_1 may be applied as follows:

Select generous quantities of two metals, as lead and copper, the freezing-points of which are accurately known. Then place the pyrometer in a bath of one of these metals and record its

resistance as the metal slowly cools. When the metal begins to freeze its temperature holds constant at the freezing-point temperature of the metal for an appreciable time, and likewise the resistance of the pyrometer holds constant over this same period. This resistance is then the resistance of the pyrometer at the known freezing temperature of the metal used, and the quantities R and t become known. Repeat with the other metal, and then the quantities R_1 and t_1 become known. Curve 3, Plate IV, shows a resistance cooling curve taken in the above manner with the pyrometer placed in a lead-bath. It should be noticed how marked is the freezing-point.

The freezing-points on similar curves for Sb, Cd, Zn, and Cu, all of which may be used to give fixed points of temperature, are even more sharply defined, and hence it is easily seen how very accurately the necessary data may be obtained for determining the constants m and R_o. In making these determinations it is advisable to use crucibles made out of Acheson graphite. They are easily constructed by drilling out, with about a one-inch drill, a rod of graphite. The walls of the crucible should not be over one or two millimetres thick, because the heat capacity of the container should be kept as small as possible. If the heat capacity of the container and pyrometer are large in comparison with the heat capacity of the metal that constitutes the bath, then if the metal is one which on starting to freeze, undercools, the temperature will not ascend again to the normal temperature of solidification. The reason for this is that heat will be taken from the bath by the container and the pyrometer while the metal is rising from its undercooled temperature to its normal freezing-point temperature. The use of a thick-walled crucible, rapid cooling of the furnace, and insufficient quantity of metal in the bath, all contribute especially in the case of antimony, which greatly undercools, toward an inaccurate determination; the temperature given to the pyrometer, at the time its resistance is recorded as momentarily constant, being lower than the true freezing-point temperature.

As an illustration of the above method of calibrating a pyrometer we record the data obtained in a particular case. The pyrometric substance employed was pure tin. This metal was chosen because it is inexpensive, its melting-point is low (232° C.) and its boiling-point very high (over 2000° C.), and because its

increase in resistance with temperature, when in the molten state, is strictly linear to at least 1680° C. and probably higher. From data taken we have:

R (resistance of pyrometer at freezing-point of copper, 1082.8° C.) $= 0.0021544$ ohm.

R_1 (resistance of pyrometer at freezing-point of antimony, 630° C.) $= 0.0018252$ ohm.

Substituting these values in the expression for the value of m gives,

$$m = \frac{0.0021544 - 0.0018252}{1082.8 - 630} = 7.268 \times 10^{-7}$$

and in the expression for R_o gives,

$$R_o = \frac{0.0018252 \times 1082.8 - 0.0021544 \times 630}{1082.8 - 630} = 1.367 \times 10^{-3}$$

and

$$\frac{R_o}{m} = 1880 = K.$$

From the expression $\frac{b}{ma} = 10^x$ we obtain, by giving to x the value 5 and to a the value 2×10^3 ohms,

$$b = ma\, 10^5 = 7.268 \times 10^{-7} \times 2 \times 10^3 \times 10^5 = 145.36 \text{ ohms.}$$

Hence, using this pyrometer with the above constants and a variable low-resistance standard, which has an upper limit for the value S of 0.1 ohm, we obtain, according to Equation (4),

$$t = S\, 10^5 - 1880, \text{ degrees Centigrade.}$$

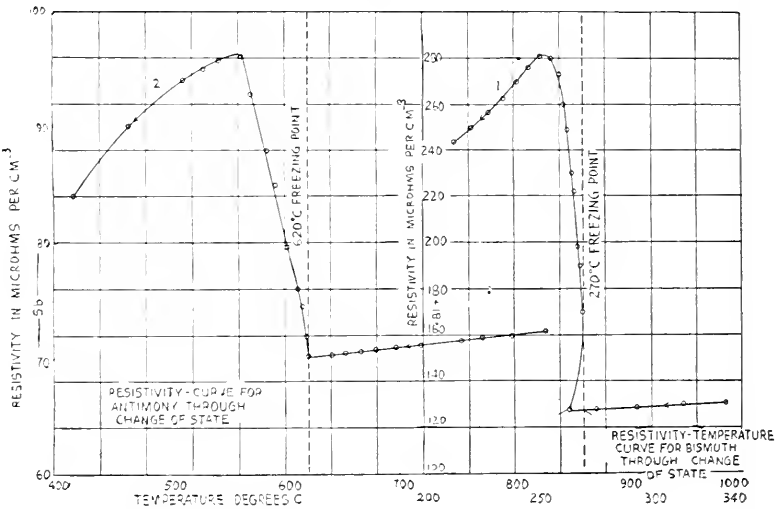
If the upper limit of S had been 0.01 ohm it would have been necessary to use the factor 10^6 instead of 10^5, and then b would have been 1453.6 ohms instead of 145.36.

When employing the resistance as a pyrometer we used the variable low-resistance standard belonging to a Leeds & Northrup Kelvin double-bridge, catalogue No. 4307, the upper limit of which is 0.1 ohm, and when using the resistometer for resistivity measurements we used a Leeds & Northrup variable low-resistance standard, catalogue No. 4300, which has an upper limit of 0.01 ohm.

OBSERVATIONS AND RESULTS.

The second-named writer, in the course of an investigation undertaken for the purpose of studying the electrical resistivity of some pure metals and also of some alloys, as these slowly changed from the liquid phase to the solid phase, and *vice versa*, has obtained some results which will serve to illustrate the usefulness and precision of the methods of measurement which have been described. It is hoped that these results, furthermore, will prove to have an interest of their own, although what is here

PLATE I.



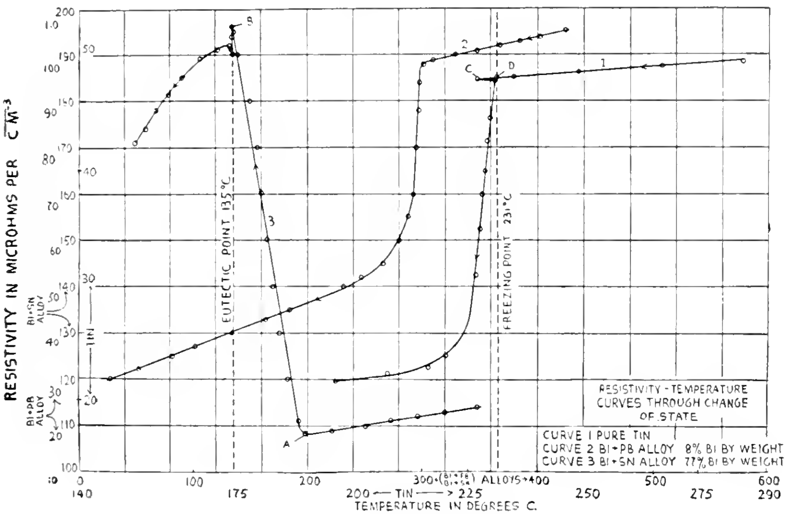
given is more or less limited in character and scope, because the research is necessarily an extended one and was only well begun at the time this article was prepared.

Curve 1, Plate IV, is a resistivity-temperature curve drawn from data obtained for pure Kalhbaum lead. The resistivity measurements were made with a type 2 resistometer, while another resistometer of the same type was used for the temperature-measuring device. This latter was filled with pure tin, which served as the pyrometric substance. The arrangement of apparatus used is shown diagrammatically in Fig. 6.

Curve 2, Plate IV, is a curve of the same character for the alloy bismuth-tin in atomic proportions. Attention is called to

the upper portion of this curve, where it will be noticed there is a sharp change, beginning at about 1140° C., from its otherwise linear character. This, very probably, is to be interpreted as the temperature at which the bismuth starts to vaporize and pass off, thus modifying the composition of the alloy. In this connection attention is directed to a phenomenon of the same character observed by the first-named writer in brass, an alloy of zinc and copper.[8] The resistivity curve of brass shows a marked inflection at about 1090° C., at which temperature the zinc began to

PLATE II.

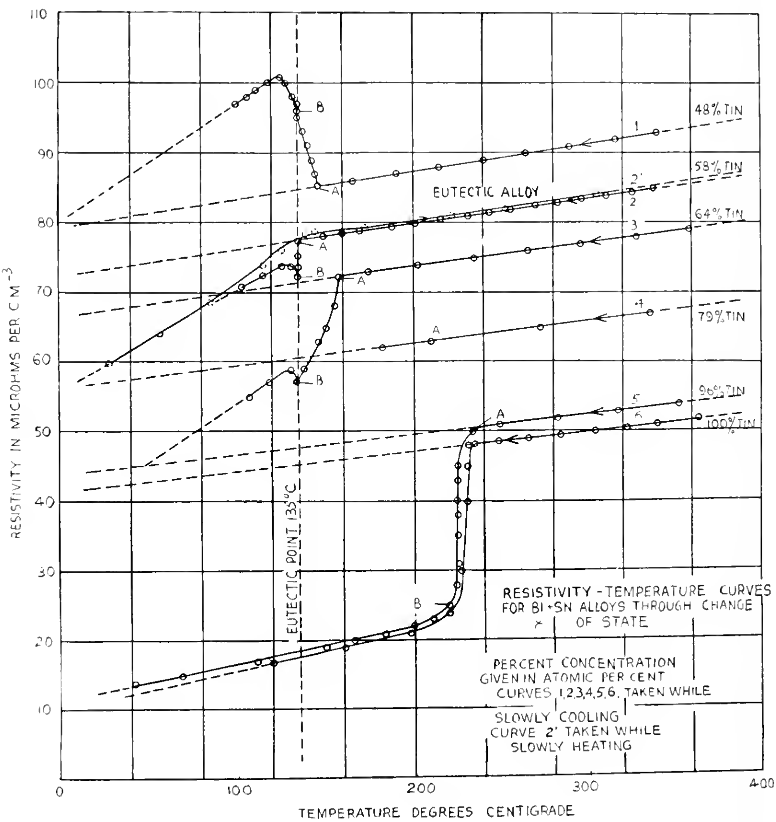


vaporize out. Curves 1 and 2, Plate I, are resistivity-temperature curves for pure bismuth and pure antimony respectively, taken as the metal cooled. Curve 1, Plate II, is a similar curve for pure tin, also taken as the metal cooled. Curves 1, 2, 3, 4, 5, 6, Plate III, and Curve 3, Plate II, are resistivity-temperature curves for various alloys of bismuth and tin. The per cent. of each component, in each of the different alloys used, is designated in connection with each of the curves. Curve 2, Plate II, is a resistivity-temperature curve of a Bi-Pb alloy containing 8 per cent. by weight of Bi.

[8] *Metallurgical and Chemical Engineering*, March, 1914, p. 161.

In all the above cases the resistivity measurements were made using a type I resistometer. The temperature measurements were all made with a copper *versus* constantan thermocouple, except with antimony, in which case a platinum-rhodium couple was employed. The hot junction of the copper-constantan couple

Plate III.



was encased in a thin-walled quartz-tube and immersed in the sample and laid close alongside the resistometer-tubes, as previously described. The calibration of this thermocouple was carefully checked at frequent intervals during the investigation and no change in its calibration was observed. Before taking any observations on an alloy care was used to thoroughly mix the sample when at a temperature of 600–700° C. This precaution

was taken to give assurance that perfect homogeneity was secured throughout the entire mass of the sample contained in the crucible E.

DISCUSSION AND DEDUCTIONS.[9]

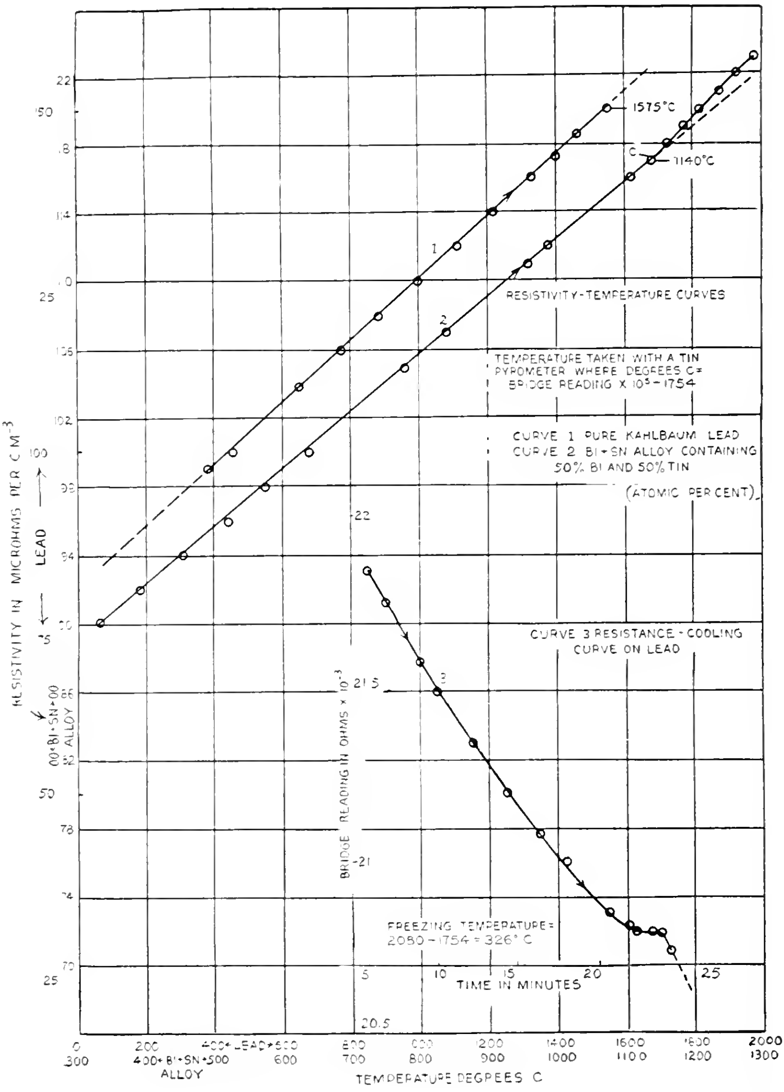
A common characteristic shown by all these resistivity-curves, both for the pure metals and the alloys, is their linear character in the molten state. Moreover, it is interesting to note that the slope $\frac{dR}{d}$ for all the curves of the Bi-Sn alloys in the molten state is approximately constant. The phenomenon of undercooling, indicated on the curves by *C D*, is clearly shown in the case of bismuth and tin (see Plates I and II). This phenomenon should also have appeared, presumably, in the case of antimony, since this metal exhibits undercooling in a marked degree. That the phenomenon did not appear on the temperature-resistivity curve is to be explained, probably, by failure to use a sufficient quantity of the metal when taking the measurements. So far as we are informed, this is the first time that the phenomenon of undercooling has been made to reveal itself on a temperature-resistivity curve when tracing this for a metal or alloy passing from the molten to the solid state.

The chief interest in the results obtained, however, is connected with the curves obtained for the alloys of bismuth and tin given in Plate III. Attention is directed to the following features:

1. The linear portion of the curves gives the resistivity-temperature relation of the alloy when this exists as a homogeneous liquid-solution. When cooling has reached the point designated by the letter *A* on all the curves, there suddenly takes place a separating out of a mixed crystal. Between the points *A* and *B* on the curves the alloy consists of this mixed-crystal and a liquid solution, the latter, however, gradually disappearing while the mixed-crystal increases in amount until the point *B* on the curves is reached. Here the last trace of liquid solution disappears and at the same instant the single mixed-crystal immediately begins to separate into two conjugate mixed-crystals. This is shown sharply on the curves. The remaining portion of the curve gives the resistivity of the alloy while the two mixed-crystals

[9] All that follows is contributed by and is entirely based on the work done by R. G. Sherwood.

Plate IV.



gradually change their relative composition, as the cooling progresses. The temperature at which the last trace of the liquid solution disappears and the two mixed-crystal formation begins is, for this class of alloys, always at the definite

fixed-temperature called the "Eutectic Point." The reason why Curve 5, Plate III, does not exhibit this common characteristic is to be explained by the fact that the proportion of the constituents is such that, after the point B is reached, the single mixed-crystal remains as an unsaturated solid-solution of bismuth in tin, for the lowest temperature recorded. Hence there is no breaking up of the alloy into the two conjugate solid-solutions or mixed-crystals above referred to. In the case of the curve for the eutectic alloy the points A and B are at the same temperature, since, by definition of the eutectic, the homogeneous liquid solution at its freezing-point does not pass into a single mixed-crystal, as do the other alloys, but passes immediately into two conjugate mixed-crystals. The character of the curve for the eutectic brings out this point well.

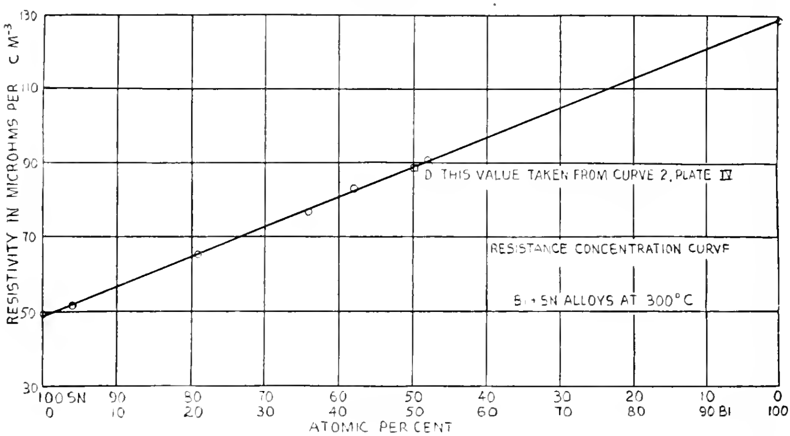
2. The heating curve for the eutectic alloy, curve 2, is interesting, since it apparently shows that the mixture represented by the proportions of this alloy are the proper proportions to "wipe out," so to speak, the abrupt break exhibited by all the other curves, as well as by the pure metals themselves. Heating-curves for these latter have been taken, but, since they differ only slightly from the cooling-curves given and seem to be of no special interest, they have not been included. The phenomenon above mentioned, associated as it is with the alloy having the lowest freezing-temperature, rather suggests some sort of a definite relation existing between the molecular condition or arrangement which causes a lowering of the freezing-point of the alloy and the molecular condition or arrangement functioning to change the resistance of the alloy.

3. When consideration is taken of the fact that the liquid phase of a metal or alloy possesses no crystalline structure, at least in the case here referred to, and is homogeneous throughout, it is logical to conclude that a systematic study of the electrical resistivity of various metals and alloys in their liquid phases might yield some very interesting and important information and furnish thereby a new basis for the comparison of this property with other properties of the metals or alloys. In this connection the curve, Plate V, is of unusual interest. This curve shows that a linear relation exists between the resistivity of the various alloys of bismuth and tin and the percentage of gramme-atoms of each constituent forming the alloy. Whether such a relation or some

other simple relation holds true for alloys of other metals is, of course, a matter of more or less speculation.

To obtain a more specific relation between the resistivity, concentration, and temperature of the alloy Bi-Sn, we can proceed as follows: Let $R =$ resistivity of an alloy of Bi and Sn at concentration c and temperature t, where c is a quantity varying from zero to unity, being unity when the alloy consists of, say, 100 per

PLATE V.



cent. tin and zero per cent. bismuth—per cent. to be reckoned as above described. The temperature will be reckoned in degrees Centigrade. Then assuming $R = f\ (ct)$,

$$dR = \frac{\delta R}{\delta c} dc + \frac{\delta R}{\delta t} dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

But on the assumption that all the resistivity-temperature curves have approximately the same slope, we may write

$$\frac{\delta R}{\delta t} = m.$$

Again, considering Equation (7) as a total differential,

$$\frac{\delta}{\delta t}\left(\frac{\delta R}{\delta c}\right)_t = \frac{\delta}{\delta c}\left(\frac{\delta R}{\delta t}\right)_c \text{ or } \frac{\delta}{\delta t}\left(\frac{\delta R}{\delta c}\right)_t = \frac{\delta}{\delta c}\left(\frac{\delta R}{\delta t}\right)_c = \frac{\delta}{\delta c}(m) = 0.$$

Here $\frac{\delta R}{\delta c} = K$ where K is a constant (see curve, Plate V). Equation (7) now can be written $dR = Kdc + mdt$, which upon

integration gives, $R = Kc + mt + p$, where p is the constant of integration.

To evaluate p, let $t = O$ and $c = O$, then $p = R_o^{Bi}$ where R_o^{Bi} is defined as the intercept of the linear portion of the resistivity-temperature curve for pure bismuth projected back to cut the R axis.

Finally then,

$$R = Kc + mt + R_o^{Bi} \qquad (8)$$

The constant K and m in Equation (8) must, of course, be obtained from the slopes of the resistivity-concentration curve and the resistivity-temperature curves, respectively.

The resistance-temperature coefficients of the alloys in the liquid phase can, of course, also be expressed in terms of the concentration c and the temperature t. While this gives no new information, it is interesting to find an expression for it. Calling this coefficient α defined as $\frac{1}{R_o}\frac{dR}{dt}$, we obtain from Equation (8)

$$\alpha = \frac{1}{R_o}\frac{dR}{dt} = \frac{K\frac{dc}{dt} + m}{Kc + R_o^{Bi}}.$$

Since c and t are independent variables, $\frac{dc}{dt} = O$, whence

$$\alpha = \frac{m}{Kc + R_o^{Bi}} \quad \text{or}$$

$$K\alpha c + \alpha R_o^{Bi} = m \qquad (9)$$

Equation (9) is obviously the equation of an hyperbola.

Referring again to Curve 2, Plate IV, it will be noticed that the resistivity of this alloy of Bi and Sn (50 per cent. Bi and 50 per cent. Sn, each being in per cent. of gramme-atoms of each constituent) at 300° C. checks exactly with the value taken from the curve, Plate V. When it is considered that the data for the former were taken with apparatus differing quite essentially from that used in the case of the latter, the agreement is indeed gratifying and illustrates fully the practical value of the methods herein described.

PALMER PHYSICAL LABORATORY,
Princeton, N. J.,
May, 1916.

Brick Chimney Strengthened by Reinforced Concrete. E. McCullough. (*Engineering Record*, vol. 74, No. 6, August 5, 1916.)—Repairs to a dangerously cracked brick factory chimney 150 feet high successfully transformed it, to all external appearances, into a concrete chimney. A reinforced concrete shell was built around the old brickwork, using the latter as interior and galvanized steel as exterior forms, without interrupting the operation of the plant. The total cost of the work was about one-half the original cost of the brick chimney. This chimney was built 14 years ago. Three years after it was erected cracks appeared without any apparent reason, which gradually increased in size until last year when they excited alarm, and threatened to cause the cancellation of insurance policies on adjacent structures.

A concrete casing 10 inches thick was placed around the square base, 37 feet in height, above the base on the tapered shaft; the concrete is 8 inches thick at the bottom and 6 inches thick at the top. The horizontal reinforcing bands consist of ½-inch bars spaced 24 inches apart. The total cost of the concrete work was $2465, and the original cost of the chimney from the ground line to the top, $4800.

Using Steam Heat for Melting the Softer Metals. R. Cramer. (*American Machinist*, vol. 45, No. 5, August 3, 1916.)—In its manufacturing process the Amalgamated Machinery Corporation of Chicago uses large quantities of type metal, an alloy of lead and antimony, for setting bearings and the like in cored castings. The alloy has a melting-point of 475° F., and it is essential that it be poured at a temperature not exceeding 550° F. Ordinary gas-heating melting furnaces such as are in common use for this kind of work necessitate the constant vigilance of an attendant using a thermometer in order to prevent overheating of the metal bath.

It was thought that by means of a coil containing steam at sufficiently high pressure, the latter being kept constant automatically, the metal bath could be kept in proper condition, ready to be drawn from without an attendant. The pressure at which saturated steam has a temperature of 550° F., is 1050 pounds per square inch. It was found, however, that to insure transfer of heat, desirable to employ a temperature of 600° F., corresponding to a pressure of 1575 pounds per square inch. An apparatus designed by Winslow Brothers, of Chicago, consisting of a receptacle carrying a steam coil for heating a cast-iron crucible connected to a high-pressure boiler of special design, heated by gas, fulfilled the requirements. The details of the apparatus have worked reliably in practical operation, and it is possible to keep the metal in a melted condition at the desired temperature, ready for instant use, without more attention than a casual glance at the pressure gauge.

A CENTURY OF LIGHT.*

BY

WALTON CLARK, M.E., D.Sc.,
President of The Franklin Institute.

MR. PAUL, the chairman of the Committee on Instruction of The Franklin Institute, has conferred upon me the honor of addressing you to-night. Since Mr. Paul has left the subject of my talk to my selection, I, as might be expected from my profession in life, have elected to speak of light, and "A Century of Light" is the subject of my story—the wonderful growth in the volume of artificial illumination in the century beginning with the year 1815, the date upon which artificial illumination began its career as a public service industry.

The lighting industry, as a public service, is all of the hundred years just ended; mainly of its latter half. In the earlier decades of the century, adventurous men spent their lives amid the perils of the Arctic, slaughtering harmless mammals, and bees were robbed and domestic animals gave their lives, that with train oil lamps and moulded tapers man might mitigate the evening's gloom. And then came gas lighting as a public service industry. The longest step in the advance of artificial illumination, from the building of the first fire to this hour, was taken when a material capable of yielding light upon combustion, requiring no storage upon the premises of the user, always ready for use, and measured as used, was made available to man. We may not deny that this long step in the art of artificial illumination was among the first of the gigantic strides with which material civilization has marched through the century.

The art of illumination by manufactured gas had its birth prior to 1815, but it did not attain the dignity of a public service industry until 1815. Nor were the discoveries made prior to 1815 of great importance, except that they demonstrated the practicability of the general distribution of what Bonaparte called "Une Grande Folie," and Walter Scott referred to as the project of a "madman," and later as a "pestilential innovation." In 1796, Philadelphia—always prominent in matters relating to the gas industry, and, except for its disastrous experiment with munic-

* Address to the Graduating Class of the Franklin Institute School of Mechanic Arts, April 14, 1916.

ipal ownership, always with an enviable prominence—had a sight of the "Folie," and it was the first sight of the wonder had in the United States.

Watson, in his Annals of Philadelphia, tells us that "The first gas made in Philadelphia, or in the United States, was manufactured by M. Ambroise and Company, Italian fireworkers and artists, and was exhibited in burning lights of fanciful figures . . . . , at their amphitheatre, Arch Street, between Eighth and Ninth, in August, 1796."

The earliest recorded attempt to provide a gas works for an American city was made by Dr. Bollman, in Philadelphia, in the first year of our century, 1815. In Philadelphia we are frequently the first to start, but sometimes we are slow on the road. Philadelphia had the first start towards the first American gas works, but Baltimore and New York had gas works before Philadelphia. And the enterprise of the Italian citizens of Philadelphia, and of Dr. Bollman—indicative each of a progressive spirit in our city—is in contrast to a protest of many prominent citizens, addressed to the Select and Common Councils, and entitled "A Remonstrance Against Lighting With Gas." This protest, which was registered in 1833, arraigned gas as a powerful and destructive agent, and the consequences of its use are called "appalling." It concludes: "In conclusion, we earnestly solicit that the lighting of our city with oil may be continued." Among the several hundred signers of this protest are many names well known to-day in Philadelphia business, social, and professional life. But the prominent gentlemen failed of their purpose, and two years later, after Mr. S. V. Merrick had studied gas lighting in Europe, and recommended it to the citizens and government of Philadelphia, Philadelphia established a gas works, with Mr. John C. Cresson as engineer. Mr. Merrick was one of the founders of The Franklin Institute, and for twelve years its president. Mr. Cresson, the builder of the first gas works in Phildelphia, was at that time one of the managers of The Franklin Institute, and later, for eight years, its president.

From the beginning of history to the beginning of our century of light there had been no radical advance in the art of nocturnal illumination. Tapers and lamps consuming oil through a wick were used when the Pyramids of Egypt were built; and tapers and

lamps using oil through a wick were—aside from what we call fires—the sole source of artificial illumination at the beginning of our century of light.

And during the first four decades of our century sperm oil and candles were practically the only illuminants used by the average city-dwelling family of moderate means. Gas was not generally to be had, and, where it might be had, was too costly for the average purse, though it was proving its value to those who could afford it, and was coming into favor as a street illuminant. During these forty years, from 1815 to 1855, there was no material increase in the amount of lighting in the homes of people of small means—the great mass of the population. Whale oil throughout these four decades sold at about 80 cents per gallon, except that from 1845 to 1855 the average price was $1.77 per gallon. This high price was due to the increasing scarcity of whales. The high price of whale oil resulted in so greatly reduced profits that ship-owners gave up the whaling business. The supply was proving far short of the demand, though the demand must have been greatly reduced by the advance in the price. Fortunately for the purse of the householder, a new lamp oil came into use at about this time, when the discovery of petroleum in Pennsylvania gave kerosene to the world, and life to the few remaining whales.

During these four decades, 1815 to 1855, tallow candles sold at approximately 15 cents per pound. There were six candles to the pound, and each candle cost 2½ cents and had a life of seven burning hours. A candle cost, therefore, about one-third of a cent per hour burned.

Light, in this country, is expressed in candle-power. Candles vary in the amount of light they give, but not greatly when under similar atmospheric conditions. The standard of illumination in England and America is the light given by a so-called sperm candle, of prescribed composition and wick, and burning at the rate of 120 grains per hour, in an atmosphere so quiet that the flame does not flutter and the sperm does not gutter. And a candle-power hour is this amount of illumination maintained for one hour. Under such conditions a wax candle will give almost exactly the same amount of light as a sperm candle—the wax candle burning approximately ten per cent. less weight of material

TABLE I.

Showing the Estimated Amount and Cost of Illumination for Family of Five (5) Persons of Average Means at Different Periods of the Century Just Ending.

Period	Character of illuminary	Unit cost of energy	Number and kind of lights	Hours per night for one unit	Total candle power hours per year	Total cost of energy	Maintenance: Material per year	Maintenance: Cost	Total cost energy and maintenance	Total cost per 1000 candles
1815 to 1855	Sperm oil	$1.054 per gal.	2 sperm oil lamps (each 7.5 c.p. 2 oz. oil per hr.) = 3 hrs. per night for one lamp; and	3	8212.5	$19.75	—	—	$21.05	$2.50
	Candles	0.161 per lb.	5 tallow candles (6 to the lb. each 175 grs. per hr.) = 1½ hrs. per night for one candle.	1½	547.5	2.20	—	—		
1855 to 1865	Kerosene	.80 per gal.	2 camphene lamps (each 8.1 c.p. 1″ wick 1.75 oz. per. hr.) = 4 hrs. per night for one lamp; and	4	11826.0	19.50	—	—	23.25	1.88
	Candles	.274 per lb.	5 tallow candles = 1½ hrs. per night for one candle.	1½	547.5	3.75	—	—		
1865 to 1875	Kerosene	.55 per gal.	2 kerosene lamps (each 10.7 c.p. 1.5 oz. per hr.) = 5 hrs. per night for one lamp; and	5	19527.5	14.30	—	—	17.72	0.884
	Candles	0.25 per lb.	5 tallow candles = 1½ hrs. per night for one candle, *or*	1½	547.5	3.42	—	—		
	Gas	2.50 per 1000 c.f.	2 open-flame gas burners (each 14 c.p. 5 cu. ft. per hr.) = 5 hrs. per night for one burner; and	5	25550	22.80	—	—	34.21	0.894
			5 gas burners = 2½ hrs. per night for one burner.	2½	12775	11.41	—	—		
1875 to 1885	Kerosene	.22 per gal.	1 round-wick kerosene lamp (38 c.p. 4.5 oz. per hr.) = 3 hrs. per night; and	3	41610	10.29	—	—	30.36	0.401
	Gas	2.00 per 1000 c.f.	1 open-flame gas burner (17 c.p. 5 cu. ft. per hr.) = 2 hrs. per night; and	2	12410	7.30	—	—		
			5 gas burners = 3½ hrs. per night for one burner.	3½	21717.5	12.77	—	—		
1885 to 1895	Kerosene	1.35 per gal.	1 round-wick kerosene lamp (38 c.p. 4.5 oz. per hr.) = 3 hrs. per night; and	3	41610	6.32	—	—	25.49	0.283
	Gas	1.50 per 1000 c.f.	3 open-flame gas burners (19 c.p. 5 cu. ft. per hr.) = 2 hrs. per night; and	2	13870	5.47	—	—		
			5 open-flame gas burners = 5 hrs. per night.	5	34675	13.70	—	—		

1895 to 1905	Gas	1.00 per 1000 c.f.	2 incandescent gas lamps (each 70 c.p. 4.5 cu. ft. per hr.) = 6 hrs. per night for one lamp; and	6	153300	9.85	2 incandescent mantles at $.35	$ .70	19.68	0.101
			5 open-flame gas burners (each 22 c.p. 5 cu. ft. per hr.) = 5 hrs. per night for one burner, *or*	5	40150	9.13	———	——		
	Electricity	0.10 per kwh.	2 carbon incandescent electric lamps (each 14 c.p. 64 watts) = 6 hrs. per night for one lamp; and	6	30660	14.02	8 bulbs at $.20	1.60	24.97	0.488
			5 electric lamps = 4 hrs. per night for one lamp.	4	20440	9.35				
1905 to 1915	Gas	1.00 per 1000 c.f.	Small income family, 1 incandescent gas lamp (70 c.p. 4.5 cu. ft. per hr.) = 3 hrs. per night; and	3	76650	4.93	7 incandescent mantles at $.15	1.05	12.19	0.073
			1 incandescent gas lamp (55 c.p. 3.5 cu. ft. per hr.) = 2 hrs. per night; and	2	40150	2.56				
			5 incandescent gas lamps (each 35 c.p. 2.5 cu. ft. per hr.) = 4 hrs. per night for one lamp.	4	51100	3.65				
			Larger income family, 2 incandescent gas lamps (70 c.p. 4.5 cu. ft. per hr.) = 6 hrs. per night for one lamp; and	6	153300	9.85	9 incandescent mantles at $.15	1.35	16.68	0.069
			7 incandescent gas lamps (40 c.p. 2.5 cu. ft. per hr.) = 6 hrs. per night for one lamp.	6	87600	5.48				
1905 to 1910	Electricity	0.10 per kwh.	2 metallized filament electric lamps (each 18 c.p. 50 watts) = 6 hrs. per night for one lamp; and	6	39420	10.94	8 bulbs at $.20	1.60	19.84	0.302
			5 electric lamps = 4 hrs. per night for one lamp.	4	26280	7.30				
1910 to 1913	Electricity	0.10 per kwh.	Small income family, 2 tungsten electric lamps (each 32 c.p. 40 watts) = 5 hrs. per night for one lamp; and	5	58400	7.30	4 bulbs at $.50	2.00	15.14	0.144
			5 electric lamps = 4 hrs. per night for one lamp.	4	46720	5.84				
			Larger income family, 2 tungsten electric lamps (each 32 c.p. 40 watts) = 6 hrs. per night for one lamp; and	6	70080	8.77				
			7 electric lamps = 6 hrs. per night for one lamp.	6	70080	8.77	4 bulbs at $.50	2.00	19.54	0.139
1	2	3	4	5	6	7	8	9	10	11

per hour. A tallow candle will burn forty-six per cent. more material than the sperm candle, and will give almost exactly the same amount of light. The tallow candle, once an important article of commerce, has practically disappeared. I believe you cannot find one on sale in Philadelphia to-day.

The conditions under which candles are ordinarily burned—being living-room conditions—cause the candles to give less light than when in a more quiet atmosphere. It is probable that the average illumination obtained from a candle in ordinary use is not greater than one-half of a so-called candle-power. But in the figures that I am now discussing, except as otherwise stated, I credit the candle with giving the amount of light that is given by a standard candle burning 120 grains per hour in a quiet and pure atmosphere.

The illuminating power of the electric light is not affected by atmospheric conditions. The illuminating power of the Welsbach burner is little affected by atmospheric conditions, except that a strong and intermittent draft will reduce its value somewhat.

I will now have put upon the screen a table presenting graphically the data that follow in the text, that you may more readily comprehend my story.

During these four decades, 1815 to 1855, the householder of average means, in American cities, had light in his home equivalent to approximately nine thousand candle-hours per annum; and the cost per family, these first forty years of our century, was approximately $22 per annum. Unless our grandfathers were better circumstanced that the average householder of their day, they paid probably $22 per year for their nocturnal illumination, and they enjoyed the equivalent of about twenty-five candle-hours lighting per night. This takes account of the expenditures made directly for illumination, and of the illumination provided by such expenditure. To this amount of light should be added whatever of the energy developed by fires maintained for heating and for cooking was utilized for illumination. In that early day and among people of small means a considerable amount of the evening work of the household and of the study of the children was done by firelight.

The decade 1855 to 1865 saw the introduction of the kerosene

lamp into the homes of people of average means. This resulted at once, in an increase of nearly fifty per cent. in the amount of illumination, without material change in its cost. Sperm-oil lamps, burning two ounces of oil per hour, average approximately 7.5 candle-light. The camphene lamp of that day, burning kerosene oil, consumed 1¾ ounces of oil per hour, and gave approximately 8 candle-power. The oil cost was approximately the average cost of sperm oil through the greater part of the preceding four decades—80 cents per gallon. There was one marked advantage in the use of the kerosene over sperm oil—the wick kept much freer from carbon, requiring much less frequent snuffing. This snuffing was a serious nuisance to the users of whale-oil lamps. The serious disadvantages in the use of the kerosene of that early period were the frequency of the explosion of the coal-oil lamps and the smell of the lamps. These were due to the presence in the kerosene of other and more volatile hydrocarbon products of the distillation of petroleum. With greater knowledge, and greater care in the fractionating of petroleum, has come a quality of burning fluid, or kerosene, that makes the kerosene lamp practically as safe as a candle, and as odorless.

The light of twenty standard candles was probably nearly the maximum amount of light in the household of people of average means during the lighting hours of these five decades—the first half of our century; and the total lighting in such a household was about nine thousand candle-hours per year. The amount of light now being thrown into this room for its illumination is about 2500 candles. The lamps now burning in this room would give in four hours as much light as our forebears—if of average financial position—used in their houses in a year of nights.

The decade from 1865 to 1875 witnessed a very material improvement in the character of the kerosene lamp and a material reduction in the price of kerosene. During these years kerosene could be purchased at 55 cents per gallon, and 1.50 ounces of the oil would maintain 10.7 candle-power light for an hour.

This—1865 to 1875—is the last decade of the tallow candle as an important factor in the domestic economy of a city-living people of average means. It is also the period in which gas became an important factor in the lighting problem of city people. The candle-hours per annum of illumination averaged 20,000 to 38,000—about three times the lighting during the first five decades

of our century. The cost per family using kerosene and candles was slightly reduced, and the cost per family beginning to use gas was increased from approximately \$23 to \$34. Gas, during that period, sold at about \$2.50 per thousand cubic feet. The maximum amount of light in the household, during the lighting hours of that decade, was about 100 candles—one twenty-fifth of the amount of light in this room at present.

From 1875 to 1885, and thereafter, the use of candles for illumination by city families of moderate means was a negligible quantity. Kerosene had been reduced to 22 cents per gallon, gas to \$2 per thousand cubic feet. At these lower rates artificial illumination had been so cheapened, and coincidently the means of families of average means had so increased, that the amount of illumination per annum rose 300 per cent. to 76,000 candle-hours, and the cost rose about seventy per cent. to approximately \$30 per year. The maximum light in the household during this decade was 140 candles, or about one-eighteenth of the light in this room.

From 1885 to 1895 kerosene dropped to 13½ cents per gallon, and gas to \$1.50 per thousand cubic feet. The greatest improvement in lighting devices ever covered in one step was given the gas consumer at this time—1885—in the Welsbach lamp. This invention of Auer von Welsbach at once increased the light-yielding efficiency of coal-gas from three candles to twenty candles per cubic foot. By this time kerosene and the kerosene lamp had been given a circular wick, and so improved otherwise as to give 38 candle-power, with a consumption of 4.5 ounces of kerosene per hour. The cost of illumination, whether with gas or kerosene, in this period—1885 to 1895—was approximately \$25 per annum for the average family.

From this time—1895—kerosene practically disappears from the domestic economy of families of average means in the city of Philadelphia, and gas and electricity take its place; gas at \$1 per thousand cubic feet, and electricity at about 10 cents per kilowatt—the gas used in Welsbach burners, and the electrical energy consumed in incandescent carbon filament lamps of 16 candle-power. Families of average means, using gas, from 1895 to 1905, had an illumination of approximately 200,000 candle-hours per year, and at a cost of approximately \$20 per annum. Families using elec-

tricity during this period had approximately 51,000 candle-power hours per year for illumination, at a cost of approximately $25.

During the last decade of our century there has been a notable improvement in Welsbach incandescent gas lamps and a more marked improvement in electric incandescent filament lamps. The efficiencies of the latter have been twice influenced—once by the introduction of an improved carbon filament, and again, and more profoundly, by the introduction of the tungsten filament. I am referring now to lamps for domestic use. There has been a further very marked improvement in the economy of electric illumination of large spaces through the use of the flaming filament arc and nitrogen-filled incandescent lamps. The tungsten filament vacuum lamp is used almost exclusively, where electricity is used, for domestic purposes, and it is the lamp that is now lighting this room.

In the last year of our century, thrifty families of five people—city residents—and of average financial strength will use for lighting, if with gas, approximately 200,000 candle-power hours per year, at a cost of approximately $14.50 per year; and a similar family, using electricity for illumination, will probably use 123,000 candle-power hours per year, at a cost of approximately $17.50 per year. The maximum light in the average household is now approximately 360 candles—about one seventh of that in this room, and eighteen times the light of a similar household in the earlier decades of our century.

These somewhat tiresome figures show that coincident with an increase of 1700 per cent. in the amount of night lighting, not including firelight, of an American city family, in average circumstances, using gas for light, there has come a reduction in the cost of the year's lighting of 34 per cent., or approximately $7.50 per year; and that the cost of lighting per unit of light—the candle-hour—is now but two and eight-tenths per cent. of what it was in the first half of our century. No other necessity of household use has been so cheapened and improved during the century.

The figures that I have just given you are my estimate of the amount and of the cost of the nocturnal illumination enjoyed in the households of people of average means, dwelling in Philadelphia. They are based in part on the memory of elderly people. They are probably very nearly correct.

If The Franklin Institute were paying current rates for small

consumers—10 cents per kilowatt—for the electric current used in the tungsten lamps, the light in this room would be costing the Institute approximately 25 cents per hour of illumination.

At the beginning of our century of light there was nowhere in the world such brilliant and inexpensive lighting as we have in this room, though there was much more beautiful lighting than that of this room, good as it is.

Washington's Birthday was celebrated in 1817 with a great ball in Washington Hall, on South Third Street, five hundred people being present. The chronicles report the room as being lighted by two thousand wax candles—giving probably a thousand candle-power. It is referred to as an instance of room lighting of great brilliance, and it must have been very beautiful. It was brilliant and costly lighting for that period, and, in my opinion, sufficiently brilliant for a ball-room of any period. If the ball continued (as I am told was the custom during the administration of President Madison) from 9 P.M. to 2 A.M., the cost of the lighting was about $150, equal to $30 per hour—two-fifths the amount of light in this room, and at one hundred and thirty-six times the cost.

The old Shot Tower, still standing near the old Gloria Dei Church, was that night illuminated with one hundred and sixty lamps. A chronicle of the day calls it a "veritable tower of light." At the best the total amount of light used in its illumination was about one thousand candles—the equivalent of about one arc electric lamp. The cost for oil used to produce this illumination was probably about $2.40 per hour of lighting.

To furnish a comparison with the above figures, I instance the lighting of this room, equalling about 2500 candles, and costing 25 cents per hour and 10 cents per 1000 candle-hours; the present lighting of the foyer of the Academy of Music, with Welsbach incandescent lamps, having a total lighting power of 3800 candles, and costing 28 cents per hour and 7 cents per 1000 candle-hours; and the lighting of the front of the office of The United Gas Improvement Company, at Broad and Arch Streets—the lamps there used being known as high-pressure, incandescent gas lamps—having a total lighting value of 16,000 candle-power, and costing 53 cents per hour and 3.3 cents per 1000 candle-hours. I cite these instances of modern illumination not with pride, nor necessarily with approval, but as evidence that the development

of the business in which I have been engaged—the public service lighting business—and the cheapening of artificial light—easily has outpaced the development of any other industry or science known at the date of its birth an hundred years ago.

TABLE II.

Showing the Estimated Amount and Cost of Street Lighting in Philadelphia at Different Periods of the Century Just Ending.

Year	Number of street and public lamps	Population	Total yearly cost of lighting to city, taking the free gas lamps as if at current prices	Approximate candle power		Approximate cost per 1,000 candle hours	Description of large units
				Total	Per capita		
1	2	3	4	5	6	7	8
						Cents	
1809	Whale oil, 1,132	58,000	$19,263.75	8,490	0.15	56.72	Sperm oil wick lamps
1850	Gas, 1,966	121,000	$43,252.00	35,388	0.29	30.56	18 C. P. gas Argand burner
1885	Gas, 14,268 Naphtha, 3,360 Electric, 198	950,000	$420,577.05	491,876	0.52	21.38	17.3 C. P. gas flat flame 14 C. P. Maloney burner Open D. C. arcs, 9.6 amperes, 47 volts
1915	Gas, 24,300 Naphtha, 19,987 Electric, 14,635	1,765,810	$2,392,935.90	17,241,359	9.76	3.47	Welsbach burners gas Welsbach burners naphtha Open D. C. arcs, 9.6 amperes

We have in this table a graphic presentation of the amount and growth, and cheapening of the street lighting of Philadelphia during the century just past.

The growth in population from 1809 to 1915 was approximately from 60.000 to 1,750,000, or nearly 3000 per cent. The increase in the amount of street lighting was approximately 200,000 per cent. The decrease in cost of street lighting per unit of light was approximately 95 per cent. The increase in the amount of light per capita of population was 6400 per cent., and the increase in cost per capita was 308 per cent. The gas lamps, for which the city does not make a cash payment, are included in these figures at current rates.

The suggestion of brighter nocturnal illumination in the streets of cities and in the houses of the well-to-do, carries nothing of inspiration to any man. There can be little joy in adding to

what already is, at least, enough. But the suggestion of a possible further reduction in the cost of nocturnal illumination—a reduction that shall mean a reasonable amount of lighting in homes now, through poverty, dark; rendering safer, more beautiful, and more cheerful the surroundings of the poor—carries much of inspiration to the engineers of the lighting fraternity. And there is promise of such reduction, cheap as artificial illumination now is—cheapened as it has been through decades that have witnessed a cheapening in little else. Small room as there is for a further reduction in the cost of gas and electricity, there is prospect of a cheapening of light through improvement in gas and electric lamps.

TABLE III.

Total Luminous Efficiencies of Light Sources.

Source	Efficiency, per cent.	
Sperm candle.......	.02	
Flat flame gas.......	.036	
Incandescent mantle gas..............	.190	
Carbon filament electric..............	.420	
Tungsten filament electric...........	1.3	
Firefly.............	*86.4	50 TIMES AREA OF THIS CIRCLE

* Assuming the efficiency of the firefly as a transformer of bodily energy into radiation is 90 per cent.

In the conversion of energy—actual and potential—through thermodynamic or chemical action—into light, there is a development of heat, necessary to the process, but greatly out of proportion to the lighting result obtained.

The whale-oil lamp converted to light one five-thousandth

part of the energy stored in the oil. The standard sperm candle also converts to light one five-thousandth part of the energy developed in its combustion. The most efficient artificial lighting unit known at the present time is the yellow flame electric arc light, and this delivers as light but one-fifteenth of the energy of the electric current producing it, and but one one-hundredth of the energy in the coal which is the ultimate source of electric energy. The lamps lighting this room convert to light but thirteen one-thousandths of the energy of the current supplied to them. The Welsbach domestic gas-lamp yields as light two one-thousandths of the energy in the gas burned in it. In these modern lighting units, the most efficient yielding to our useful purposes but seven per cent. of the energy delivered to it, and the least efficient—to my eye the most beautiful—yielding but two-tenths of one per cent. of the energy delivered to it—it is evident there is an opportunity for further economies, greater, perhaps, than those offering in any other field of industry. The brains and hearts of men of the highest scientific attainment are devoted to this opportunity—not of making brighter the places already bright, but of so cheapening artificial light that they who, through poverty, now sit in nocturnal darkness may have light; and that what light is had, and by whatever class had, may be so applied to use as to simplify the lives and beautify the surroundings of the users. The possibilities of improvement are somewhat indicated by the fact that the lamp of the fire-fly has an efficiency of 86 per cent.—twelve times greater than the most economical of our sources of artificial light.

Young men, I deem it my duty, in this day of conflict, of unrestrained national passion—though I stand in the Quaker City, and in the hall of an institution for whose existence Quakers are largely responsible—to speak to you a few words of the condition of our nation and of what, in a military way, our nation may reasonably expect from us in its day of danger.

Each of the certificates that will be given to you to-day bears three wood-cuts. Two of them are indicative of what the charter of The Franklin Institute declares to be its function—the promotion of the mechanic arts. The third wood-cut is a figure of Liberty leaning on the shield of our country. This figure and shield indicate the expectation of the founders of our institution that the young men who graduate from our school will have an

interest beyond that concerning their immediate means of livelihood; an interest in the safety, honor, and welfare of the American Republic, and in its means of defense.

You, young men, workers in the industries by day, have given evidence, by your work in our schools at night, of a discipline and self-denying spirit that are a gratification and inspiration to those who know of it. It is to men of this discipline and of this spirit, wherever and however had, that our nation must look for help in its present time of need. You, by reason of the evidence you have given of this discipline and this spirit, are marked men among your associates. Accustomed to looking toward the future and working for a future good, your kind, of all men, should be the first, after the soldier and sailor defenders of our flag, to foresee a peril and to sound the alarm. After the soldiers and sailors, your kind should be found most nearly ready and conditioned to do a part in the defense of the nation.

I think we must believe that our government will finally adopt a policy of preparedness for war that will insure the future peace of the nation. This certainly will be if our lawmakers are convinced that their constituents demand it. As far as we can, let us help them to this conviction.

And, however this may be, let us highly resolve that whatever our nation, as a nation, may do; however adequate or inadequate may be the measures it takes to protect our homes and our liberties, our country will find *us*, in its time of need, ready, at its call, to stand with our lives and our fortunes "between our loved homes and the war's desolation." And, my friends, let each man of us further resolve so to live that the service and the life he will have to offer his country in her hour of trial shall be as useful to her as, in God's providence, he is able to make them.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE FREEZING POINT OF MERCURY.[1]

By R. M. Wilhelm.

The temperature at which mercury freezes is of importance in thermometry. It marks the lower limit to which mercurial thermometers may be used, and its location at about $-39°$ C. makes it of value as a fixed point of the temperature scale below $0°$ C. A paper by the Bureau of Standards and which is now in press gives the result and describes in detail the method used in making a redetermination of this constant. The temperature measurements were made by means of platinum resistance thermometers whose constants had been previously determined by calibration at $0°$, $100°$, and $444.6°$ (the boiling point of sulphur). All the evidence at present available indicates that the platinum resistance thermometer calibrated as above, defines temperatures in agreement with those given by the standard gas thermometer down to $-40°$. The value obtained at the Bureau, $-38.87°$, is in very good agreement with that found by Henning in 1913 at the Reichsanstalt, Germany, who also used platinum resistance thermometers and obtained $-38.89°$.

THE SACCHARIMETRIC NORMAL WEIGHT AND THE SPECIFIC ROTATION OF DEXTROSE.[2]

By Richard F. Jackson.

Pure dextrose was prepared from starch conversion products and from invert sugar solutions. After a preliminary purging had removed a great portion of the adhering impurities, the substance was dissolved to form a 60 per cent. solution in water and the crystals allowed to form slowly during continuous agitation. Two or three recrystallizations were sufficient to produce dextrose of high purity. A portion was subjected to a fractional crystallization and another portion precipitated by ethyl alcohol. The various purified samples showed essentially identical properties.

Dextrose crystallizes from water solution with one molecule of water of crystallization which it loses very readily at 60° C.

* Communicated by the Director.

[1] Scientific Paper No. 294.

[2] Scientific Paper No. 293.

The residual moisture was removed by heating in a vacuum at 60° – 80° C for several hours.

To prepare the solution for polarization approximately the quantity required was weighed and dried in a weighed volumetric flask and the solution made up to the graduation mark of the flask at 20.0° C. From the data obtained the densities of dextrose solutions were calculated and found to correspond to the formula:

$$D\frac{20^\circ}{4^\circ} = 0.99840 + 0.003788\ p + 0.00001412\ p^2$$

where p is per cent. anhydrous dextrose by weight in vacuo. The formula is valid for values of p between 5 and 30.

The solution was allowed to stand over night at room temperature in order to destroy the mutarotation.

Twelve independent measurements were made to determine the weight of substance which, contained in 100 cc. of solution, would cause a rotation of 100° S on the scale of the quartz-wedge saccharimeter. If the latter is controlled by the conversion factors determined by Bates and Jackson,[1] namely 34.620° for $\lambda = 5892.5$ A or 40.690° for $\lambda = 5461$ A or by the rotation of 26.000 g. of pure sucrose in 100 cc. the normal weight of dextrose is 32.231 g. weighed in air with brass weights. If the saccharimeter is calibrated by the Herzefeld-Schönrock factor 34.657° which Bates and Jackson have shown to be in error, the normal weight of dextrose is 32.264 g.

For more dilute than normal solutions the rotations deviate from proportionality. It is therefore necessary to apply corrections to make the scale reading indicate the per cent. of substance. At 90° S the correction is +0.20; at 80°, +0.35; at 70°, +0.46; at 60°, +0.53; at 50°, +0.55; at 40°, +0.53; at 30°, +0.46; at 20°, +0.35; at 10°, +0.20.

The rotation of the normal solution (32.231 g.) for $\lambda = 5461$ A is 40.898°. Since the normal quartz plate rotates 40.690° it is evident that there is a considerable divergence between the rotary dispersion curves of dextrose and of quartz. Thus when the quartz-wedge saccharimeter is set for a photometric match the field is slightly heterochromatic and the degree of reproducibility of the setting is necessarily less than that of sucrose whose

[1] *J. Wash. Acad.*, vi, p. 25 (1916); Bull. Bur. Standards 13, p. 67 (1916).

dispersion curve coincides more closely to that of quartz. This difficulty is only overcome by an increased number of settings and by some preliminary experience on the part of the observer.

The specific rotation which is a function of the concentration of dextrose corresponds to the formula

$$\left[\alpha\right]^{20.0}_{5461\text{A}} = 62.032 + 0.04257c$$

where c is grams of anhydrous dextrose weighed in vacuo and contained in 100 cc. of solution

or

$$\left[\alpha\right]^{20}_{5461\text{A}} = 62.032 + 0.04220p + 0.0001897p^2$$

where p is per cent. dextrose by weight in vacuo.

Apparatus for Determining Hardness of Metals. ANON. (*The Mechanical Engineer* (Manchester), vol. 38, No. 967, August 4, 1916.)—A simple device for testing the hardness of metals has been designed by Messrs. Vickars, Ltd., and R. L. Smith. It consists essentially of a square steel bar of known hardness against one face of which a steel ball is held in contact by a clip attached to a yoke fitted to the other faces of the bar. The clip is elastic so that the ball and yoke can be snugly held at any point along the length of the bar. To obtain the approximate hardness of an article under examination, the apparatus is placed with the ball resting against the article, and the yoke is given a light blow with a hammer. If the resulting indentation on bar and article to be tested are alike, the hardness of the material is that of the standard bar. If, however, there is any appreciable difference in the two impressions, the operation is repeated with a harder or softer bar until equal impressions are obtained, the figures marked on the end of the bar then giving the hardness possessed by the article under examination. For each successive test the yoke is moved along the bar until the ball rests upon an unindented surface. A pointer formed on the spring clip is provided. This is brought in register with the inner edge of the last impression and determines the nearest position of the next impression without danger of overlapping. The chief utility of the device is in ascertaining whether the hardness of an article lies between the limits determined by that of two standardized test bars.

A New Light Matching Pyrometer. ANON. (*Scientific American,* vol. cxv, No. 7, August 12, 1916.)—By comparing the intensities of colored light, one of known value and the other of a value that is to be determined, a recently developed pyrometer makes possible the measuring of the temperature of a heated body either within or without a furnace. The new pyrometer, although sufficiently compact to be carried about in the pocket, duplicates the color of heated bodies and at the same time indicates the temperatures on a calibrated scale with an error limit of one to two per cent. In general contour the apparatus is cylindrical, about 2 inches in diameter by 8½ inches long.

In operation it is held in the hand, and the body whose temperature is to be measured is viewed through a peep-hole near the end. Upon pressing a button a small incandescent lamp, supplied with current from a battery carried in the case of the pyrometer, throws a beam of light which passes through a screen of varying transparency and impinges in an inclined mirror that is visible when looking through the peep-hole. While the light is turned on, the observer manipulates one or the other of two knurled knobs, causing a graduated screen to be moved from one roller to another, bringing a lighter or darker section over the lamp aperture. When the two colors seen through the peep-hole appear to match, a reading is taken with the light still on. The numbers representing the various temperatures form part of the graduated screen and hence appear on the mirror. The light intensities as viewed through the pyrometer appear as different shades of blue. This color has been chosen for the reason that it lends itself well to making exacting comparisons between various shades.

Non-recoil Guns for Aeroplanes. ANON. (*Machinery,* vol. 22, No. 12, August, 1916.)—The two factors that limit the power of the armament for aëroplanes are the force of the recoil and the weight of the weapon. In order to overcome these limitations, the non-recoil gun has been developed, and its tests have thoroughly demonstrated that, regardless of calibre, there is practically no recoil force. The absence of recoil is due to the fact that, instead of having the gun closed at the breech end, it is left open by substituting a complete barrel for the usual breech-block, and firing through this barrel to the rear a charge of fine shot (equal in weight to the front projectile) that quickly scatters and loses its velocity. In this way the action and reaction are equal, so that there is no tendency for the gun to move in either direction. The powder charge is so arranged that it is all in one chamber, and ignition and combustion of the two charges are necessarily simultaneous. The elimination of the shock of the recoil makes it necessary to consider only the question of weight in limiting the size of an aëroplane gun. Many of these guns are now being built for foreign governments by the General Ordnance Company, Derby, Conn.

NOTES FROM NELA RESEARCH LABORATORY.*

THE REVERSAL OF A FADED NEGATIVE AFTER-IMAGE BY BRIGHTENING THE STIMULUS FIELD.

By Leonard T. Troland.

If the stimulus field upon which a negative after-image is projected is suddenly darkened, the luminosity contrast between the image and its surroundings is greatly enhanced. If, on the other hand, the field is brightened, the contrast is diminished, and, under the right conditions, will be *reversed,* so that the image becomes *positive.* The experiments described below were made to determine the influence of color and intensity upon this latter effect.

The after-image was produced by fixation of a semicircular field, 3 1/3 degrees in diameter, on a dark background, for 30 seconds, at the end of which time the full circle was exposed, fixation being maintained on the central point. Three seconds later the entire field was dimmed to one-tenth the primary intensity, and held at this value for 45 seconds, at the end of which time the original intensity was restored. At this instant the reversal appeared, if at all. When present, its duration was measured.

Eight spectral colors, at seven different intensities, were employed as stimuli. Six trials were made for each setting, and the results are shown in the following table. Under P is given the number of times a reversal was seen, under N the number of negative contrasts observed. T is the net average duration of the positive; *i. e.,* the sum of the duration of the positives minus the sum of the duration of the negatives, divided by the total number of cases. T is not calculated for the shorter wavelengths, on account of the small probability of significance of the values for these stimuli.

*Communicated by the Director.

INTENSITY IN PHOTONS.

Color and wave-length in $\mu\mu$	6.40	16.00	40.00	100.0	250.0	625.0	1560
Red:							
676.4–7000							
P.	2	6	6	6	6		
N.	3	0	0	0	0		
T.	0.5	2.9	4.4	13.2	9.1		
Orange:							
614.4–631.0							
P.	1	4	4	5	5	6	2
N.	3	0	0	1	1	0	3
T.	0.13	1.4	1.7	4.0	5.4	6.8	−1.3
Yellow:							
569.2–582.0							
P.	1	0	2	1	3	5	6
N.	2	3	2	2	2	1	0
T.	0.0	−1.0	−0.5	−0.1	0.5	9.9	12.4
Yellow-Green:							
534.6–545.0							
P.	1	0	0	1	5	6	6
N.	1	1	3	1	1	0	0
T.	0.0	−0.2	−0.4	0.2	3.1	5.9	5.5
Green:							
500.5–509.0							
P.	0	3	2	1	2	1	1
N.	0	2	1	1	1	1	0
T.	0.0	0.2	0.8	0.2	0.3	−0.03	0.3
Blue-Green:							
485.4–493.0							
P.	1	1	1	1	2	0	
N.	0	1	1	1	0	0	
Blue:							
465.0–485.0							
P.	3	3	2	0	1	1	0
N.	1	1	1	1	1	1	0
Violet:							
424.0–436.7							
P.	2	1	2	2	2		
N.	2	0	2	1	1		

It will be observed that a distinct law governs the appearance of the phenomenon; it is present most strongly in the long-wave end of the spectrum, and with decrease in the wave-length higher and higher intensities are required to bring it out, so that in the short-wave end it is practically absent with the intensities here employed.

The writer acted as subject in the above experiment, the exposures being controlled by an automatic apparatus. The flicker photometer was employed for the establishment of intensities.

Nela Park, Cleveland, Ohio,

September 7, 1916.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

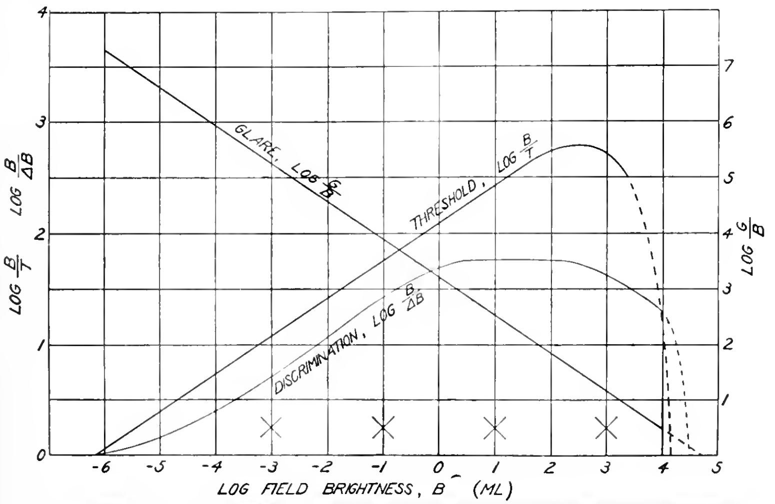
THE EFFECTS OF BRIGHTNESS ON VISION.

By Dr. P. G. Nutting.†

[*Abstract*]

THE eye adapts itself readily to a range of brightness from about 10^{-6} millilamberts (absolute threshold) up to about 50 lamberts, which is a little brighter than white paper in direct sunlight. This adaptation is in the nature of an automatically varying sensibility. Numerical data on this variation in sensibility have been obtained for the whole range of adaptation and are given below.

The three kinds of sensibility of more interest at any brightness level are (1) the lowest visible low light (2), the lowest perceptible contrast and (3) the highest tolerable highlight or Threshold, Discrimination and Glare Sensibility. Our data are given in the accompanying table and figure.



* Communicated by the Director.

† Communication No. 38 from the Research Laboratory of the Eastman Kodak Company.

TABLE—VISUAL SENSITOMETRIC DATA.

Field Brightness	Different Fraction	Discrimination Factor	Threshold Limit	Glare Limit ml.
0.000001	(1.00)	1.0	0.00000093	20.1
0.00001	(0.66)	1.5	0.0000042	40.7
0.0001	0.395	2.5	0.000019	89.0
0.001	0.204	4.5	0.000087	186.0
0.01	0.078	12.8	0.00039	400.0
0.1	0.0370	27.0	0.00174	810.0
				l.
1.0	0.0208	48.2	0.0081	1.66
10.0	0.0174	57.5	0.036	3.47
100.0	0.0172	58.1	0.28	7.25
1,000.0	0.0240	41.7	2.15	14.45
10,000.0	(0.048)	(20.9)	(232.0)	30.90

ROCHESTER, N. Y.,
Sept. 21, 1916.

PROPORTIONAL REDUCERS.*

By Kenneth Huse and Adolph H. Nietz.

[*Abstract*]

Photographic reducing solutions may be divided into three classes: (1) those which attack the highest densities most, (2) those which attack the lowest densities most, and (3) those which reduce all densities in the same proportion.

Norman Deck has recently suggested that by the use of a mixture of potassium permanganate and ammonium persulphate a satisfactory proportional reducer could be obtained, belonging to the third class. This has suggested the present investigation on reducers generally and especially on the best formula for a mixture of potassium permanganate and ammonium persulphate to give proportional reduction.

Sensitometric strips of various plates were exposed, developed and reduced in a thermostat under an accurately controlled condition, the plates being first developed, fixed, washed and dried and then, after measurement, reduced, dried and read again. The percentage of the original density removed by reduction from each step of exposure was plotted against the logarithm of the exposure. The results show that persulphate is the only reducer which removes a greater percentage of the higher densities; and that all others tried, including some which have been supposed to work proportionally, really reduce the lower densities most,

* Communication No. 39 from the Research Laboratory of the Eastman Kodak Company.

so that they tend to remove the shadow detail, the reducer having the greatest influence in this direction being a solution of ferricyanide and thiosulphate, which reduces the shorter exposures to such an extent that its effect on the curve through the greater part of its action is exactly as though less exposure had been given to the plate, this reducer being very useful for correcting over-exposure.

After a trial of various proportions of the permanganate and persulphate mixture suggested by N. Deck, the following formula was adopted as giving the most evenly proportional reduction:

Sol. A.	Potass. Permanganate	0.25	gms.
	10 per cent. sulphuric acid	15	cc.
	Water	1000	cc.
Sol. B.	Ammonium Persulphate	25	gms.
	Water	1000	cc.

Use 1 part of A to 3 of B. The solutions will keep well and should not be mixed until ready for use. The time of reduction required will be from one to three minutes, depending on the amount desired. Reduction should be followed by immersion for five minutes in a one per cent. solution of potassium metabisulphite. The plate should then be washed for a short time.

In the course of this work it was observed that the result obtained depended to a considerable extent upon the nature of the emulsion used, even this proportional reducer showing greater action on the low densities in the case of a slow, fine-grained plate.

ROCHESTER, N. Y.,
SEPT. 19, 1916.

Sources of Nitrogen Compounds in the United States. C. G. GILBERT. (*Proceedings of the Smithsonian Institution,* June 30, 1916.)—Nitrogenous compounds are essential not only to self-defense but to the country's capacity for self-support, and to be effective the source must be such that the product may be adaptable to meet their requirement. The arc method of producing nitrogen compounds has not thus far demonstrated capacity to meet the agricultural requirement at all or even the defense requirement efficiently. Definite knowledge concerning the Haber process is lacking, but its record of achievement is against it, and it would seem, moreover, unsuited to American conditions, at least in the present

state of its development. The cyanamide process is capable of a development which will meet the requirements for a cheapened nitrogenous fertilizer source whose form of nitrogen content is readily convertible to nitric acid. The process is already a prominent factor in the economic well-being of most countries of older civilization, and is capable of similar extension in the United States.

By-product coking operations afford a source of nitrogenous compounds netting the country an annual production at the rate of over 200,000 tons of ammonium sulphate now, and due to raise this total to about 400,000 tons with the completion of the ovens now building. A total of about 700,000 tons would be possible if all coking were of by-product nature, and this total should be attained within the next few years. No practicable means for its oxidation to nitric acid have yet been found in this country. By-product ammonia constitutes the country's one actual asset in the form of nitrogenous compounds. It has a rapidly growing yield of very great importance in itself, but of even greater importance as a factor contributing largely to the commercial possibilities of a number of industrial lines, especially that of coal products. The country cannot afford to run any risk of checking development along these lines. The evolution of a practicable process for the oxidation of by-product ammonia to render present resources available, with the development of an atmospheric nitrogen fixation output by the cyanamide process carefully timed to meet growing demands following a reduction in the retail price of nitrogenous fertilizer, would appear to be the desirable governmental procedure as being the one least liable to disastrous consequences.

A Sensitive Magnetometer. P. E. SHAW and C. HAYES. (*Proceedings of the Physical Society of London,* vol. xxviii, part v, August 15, 1916.)—A torsion balance of extreme delicacy carries a pair of purest silver balls, each 3 grains weight. A solenoid with horizontal axis passing through one of the silver balls is brought close to the balance. On exciting the solenoid, divergent fields of known strength are obtained in the region of the ball. The resulting attraction of the ball to the solenoid is shown by a mirror reflecting a distant scale to a telescope. The couple on the torsion beam required to produce 1 millimetre scale deflection is 4.5×10^{-7} dyne-centimeters, and this torsion balance is 10^{6} times as sensitive as any known to have been used previously in this kind of work.

The results of these experiments are: (1) The magnetic properties of silver are ascertained even for weak fields of 1 to 10 gausses. (2) The silver has a pronounced retentivity, this effect being presumably due to the small trace of iron impurity. (3) The relation of susceptibility of the silver to the field used is found. The susceptibility of each of the constituent materials, pure silver and residual pure iron, appears to be greatly modified by the presence of other material.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE PLIOTRON OSCILLATOR FOR EXTREME FREQUENCIES.

By William C. White. [1]

The physical construction of the pliotron and its operation in various arrangements of circuits are described in detail with cuts. The connections for the production of frequencies as low as ½ cycle per second and as high as 50 million are shown by diagram and discussed. This latter frequency corresponds to a wave-length of 6 meters. The electrical conditions and methods for their measurement in such circuits are given.

THE LAW OF ABSORPTION OF X-RAYS AT HIGH FREQUENCIES.

By Albert W. Hull and Marion Rice. [2]

Measurements on "white" radiation from a tungsten target dispersed by a rock salt crystal, made by means of the ionization chamber, confirmed for copper and aluminum, the validity at even these short wave-lengths, of the law that the coefficient of absorption of metals varies approximately as the cube of the wave-lengths, except in the immediate vicinity of one of the wave-lengths characteristic of the metal. For lead the absorption of wave-lengths longer than 0.149 A. U. obeys the law, but below this wave-length excitation of the K fluorescent radiation begins.

Calculation of the "corrected absorption coefficient" or "transformation coefficient" shows that it is, for all substances and wave-lengths yet investigated, equal to a constant, peculiar to the substance, times the cube of the wave-length, over the entire range between absorption bands.

A table of the observed and calculated values for the mass absorption coefficients of aluminum, copper and lead at various wave-lengths from 0.392 to 0.122 A. U. is given.

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* Communicated by the Director..

[1] General Electric Review, 19, 771-5, Sept., 1916.

[2] Physical Review, 8, 326-8 (Sept., 1916).

The "Kick" of the Gun. E. C. CROSSMAN. (*Infantry Journal*, vol. xiii, No. 1, July–August, 1916.)—Not the most pleasant part of shooting a military rifle is the vicious backward drive of the steel-shod butt against the muscles of the shoulder when the trigger is pressed. Experiments at the American School of Musketry at Monterey demonstrated that the limit of endurance under normal conditions lay at about three hundred rounds a day. From every standpoint—recoil, weight of ammunition, weight of rifle, and cost of ammunition—the smaller calibres than the present 0.30 of the American service are being proved desirable.

The "kick" of a rifle is purely a matter of the equal reaction of powder gases upon the bullet and the breech-closing mechanism. The final blast of the gases of the explosion against the comparatively solid body of air aids in the backward thrust of the rifle. In the American service, the formula for obtaining the backward speed of the rifle is as follows:

$$vW = Vw + 4700\ W^1$$

where v is the recoil velocity and V the muzzle velocity of the bullet in foot-seconds, and w the weight of the bullet, W^1 the weight of powder, and W the weight of the rifle, in grains. The American service rifle has a recoil velocity of 10.2 feet per second, which gives a recoil energy of 14.6 foot-pounds. While a grown man, husky and inured to hardships, is sensitive to the recoil of the service rifle, and while about three hundred rounds is the limit for a day's firing, strangely enough the recoil in foot-pounds of the 12-bore shotgun and the normal trapshooting cartridge is nearly double that of the rifle and is taken without a murmur by the thousands of trapshooters about the country. Evidently the position has most to do with the difference in the discomfort from the recoil of the two arms; the shotgun is fired with the muscles tensed and body moving—in other words, the shock is taken by the set of tensed springs; the rifle is fired with the muscles relaxed, fired deliberately. The shotgun has also a straighter stock, thus bringing the line of resistance nearer to the direction of recoil.

The noise of the military rifle, particularly the American 24-inch barrel Springfield, is very violent. The Maxim silencer has much effect in reducing the recoil, the theory being that the gases impinging on the disks of the cylinder actually drag up the rifle and help to resist the backward thrust of powder gases within the bore, as well as to eliminate the position of the recoil caused by the gases impinging on the resisting air at the muzzle. So the silencer works in two ways—in one by cutting down the weight of the thrust, in the other by relieving the nervous system of the shock from the report, which is actually painful to some ears. The fact that military authorities dislike to take up a rifle and cartridge giving more than 15 foot-pounds recoil energy, and the fact that lightening both rifle and ammunition is urgently needed, both go to show that the next change in our rifle should be toward a still smaller calibre than the 0.30—either the 0.25 or the 0.23.

NOTES FROM THE PHYSICAL LABORATORY OF THE UNITED GAS IMPROVEMENT COMPANY *

LIPPMANN FILMS AS MEANS FOR SECURING MONOCHROMATIC LIGHT IN PHOTOMETRY AND OPTICAL PYROMETRY.

By Herbert E. Ives.

SOME years ago the writer found that Lippmann color photographs of monochromatic light could be prepared in such a way as to make the light reflected from them of a high degree of purity[1] The special features of the procedure consisted in development with a developer which would act throughout the depth of the film and subsequent bleaching of the film by mercuric chloride.

The special Lippmann photographs reflect a portion of the spectrum so narrow as to appear like a line when examined by a small spectroscope. When the angle of observation is changed the wave-length of the reflected light shifts, moving further toward the blue the greater the angle.

The present work consists in the use of these sources of monochromatic light, first, as a means of carrying out Crova's method of color-difference photometry, second, as a substitute for the spectroscope or colored glass in the optical pyrometer.

In Crova's method of color-difference photometry the photometric field is observed by monochromatic light of a selected wave length for which the intensity of the two illuminants under comparison is as their total luminous intensity.[2] This wave-length varies slightly with the light sources measured, so that no single color screen or other device giving a fixed wave-length is entirely adequate. In using the Lippmann film for this purpose a special eye-piece carrying the film permits this to be rotated to the correct wave-length, thereby meeting the requirements for both monochromatic light and for a small range of variability of wave-length according to the illuminants compared.

For optical pyrometry the Lippmann film offers a simple substitute for colored glasses giving light as monochromatic as does the usual spectroscope as employed for this purpose.

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* Communicated by the chief Physicist.

[1] "An Experimental Study of the Lippmann Color Photograph," Ives, *Astrophysical Journal*, June, 1908, p. 325.

[2] "The Application of Crova's Method of Colored Light Photometry to Modern Incandescent Illuminants," Ives and Kingsbury. *Trans. Illum. Engr. Soc.*, November, 1915, p. 716.

THE LUMINOUS EFFICIENCY OF THE RADIATION OF THE ELECTRIC ARC.

By Enoch Karrer.

THE work described in this paper is a completion of the work described in a previous paper on the luminous efficiency of the radiation of the ordinary light sources. (Physical Review, Vol. V, No. 3, March 1915, p. 189).

In the former the ordinary gas and electric light sources were studied. In the present work the electric arcs are the subject of study.

The luminous efficiency of the radiation is the fractional part of the total radiation that passes through an absorbing solution whose spectral transmission curve is identical with the luminosity curve of the eye.

Proper correction must be made for the absorption by the liquid of the radiation at the wave-length of maximum transmission.

Due to the fluctuations in the arc the method previously employed is not satisfactory.

By means of two thermopiles the total radiation and the radiation after passing through the solution may be measured approximately simultaneously.

The solution employed is not the one employed previously. The cell is one described in detail by Ives and Kingsbury (Phys. Rev. Nov. 1915, p. 319). It consists of a tank 1 cm. thick containing a solution of Copper Chloride, Potassium Chromate and Cobalt Ammonia Sulphate, together with a water tank 2.5 cm. thick to absorb all infra-red radiation.

Some of the values given for the luminous efficiency are as follows:

	Per cent
For the ordinary D. C. 110 volt solid carbon arc from...	0.34 to 0.97
For luminous yellow flame D. C. cored carbons.........	4.9 to 7.1
For luminous yellow flame arc A. C....................	4.1 to 8.3
For yellow flame, homogeneous carbons, A. C...........	11.5 to 22.5
For white flame, homogeneous carbons, A. C.	6.8 to 7.4
For yellow flame, homogeneous carbons, D. C...........	18.4 to 19.3
For white flames, homogeneous carbons, D. C.	9.5 to 13.0
For magnetite arc.....................................	5.1 to 7.4

All of the measurements were made in a horizontal direction from the arcs.

AN IMPROVED VISUAL ACUITY TEST OBJECT.

By Herbert E. Ives.

THE visual acuity test object described by the writer some time ago,[1] and since employed in various pieces of research in physiological optics, consists of two superposed opaque line transmission gratings on glass. The spacing of the ruled lines is so fine that they are not separately visible at the appropriate working distance, but when the gratings are rotated with respect to each other about an axis perpendicular to their faces, parallel dark bands are seen, whose distance apart varies continuously with the angle of rotation. The angular separation of the bands when just visible is a direct measure of visual acuity.

The apparatus has recently been improved by the use of cross-line in place of single-line gratings. By this means the pattern, instead of being parallel bands, is made up of squares which expand or contract as the gratings are turned.

As the apparatus is constructed one cross-line grating is fixed in place, and either a single-line or cross-line grating may be used at will opposite to it, so that either parallel bands or squares are obtainable. The scale on which the angle of rotation of the gratings is read is divided to read directly in Snellen acuity units, in place of the clumsy fractions used by ophthalmologists as a consequence of the limitations of the alphabetical test charts.

THE THEORY OF TEMPERATURE MEASUREMENT BY THERMOCOUPLES OF GRADUATED SIZE.

By E. F. Kingsbury.

DURING the investigation of the temperatures assumed in a flame by mantles of various compositions, the author has made extensive use of Heræus platinum-platinum-rhodium couples of four different sizes. All is well known, when these are placed against the mantle they will assume different temperatures, depending upon their size, and when their diameters are plotted against the temperatures as abscissæ a continuous curve concave upward is obtained which, when extended to zero diameter, gives a limiting temperature to the mantle wall. Consistent results have been obtained yielding many smooth curves.

[1] "A Visual Acuity Test Object," Ives, *Electrical World*, April, 14, 1910, p. 939.

An explanation of the shape of these curves has been sought, assuming the couple and mantle surrounded by a film of gas through which the heat is conducted. An expression has been obtained that gives the shapes of these curves as obtained experimentally. It has been of assistance in showing the shape of the curves from zero to the smallest diameter.

The theory has also been extended to cover the temperatures assumed by mantles of various emissive powers when placed in a flame of known temperature. Here it has been assumed that the mantle is heated in much the same manner, except that outside the mantle the flame has been cooled in many cases at least nearly to the mantle temperature. This wall of flame protects the mantle from convected and conducted heat losses. The radiation efficiency calculated for the higher temperature mantles agrees with that actually measured experimentally. It has been found that the total emission per unit area per steradian is nearly a linear function of the temperature assumed in a flame. The theory in the light of the experimental curve is interesting as helping to explain the mechanism of a flame heating a mantle placed in it.

VISUAL DIFFUSIVITY.

By Herbert E. Ives.

In developing a theory to account for the behavior of the eye toward intermittent stimuli, the writer was led to postulate for visual mechanism a coefficient of diffusivity,[1] similar to the coefficient which holds for heat, electrical and all other forms of conduction through matter. By virtue of this finite diffusivity intermittent stimuli are greatly smoothed out before reaching the brain. From the phenomena of flicker it was deduced that this visual diffusivity must vary as the logarithm of the intensity of the stimulus and at a different rate for different colors.

The present study deals with a much simpler case than that of intermittent stimuli, namely that of single flashes of light. The physical illustration is that of instantaneously applied heat sources, a case which has been completely handled mathematically. According to this treatment it follows that if two simultaneously applied stimuli are transmitted by media of different diffusivity

[1] "Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1914, p. 708, April, 1916, p. 290.

they will be transmitted at different speeds. In the case of light this would mean that two differently colored simultaneous flashes, for instance red and blue, would be seen as occuring one after the other.

This idea was tested by means of red and blue glasses carried radially on a slowly rotating disc. It was found that the theory was very strikingly borne out, the blue image lagging after the red. The amount of this lag varies with the brightness as it should according to the theory.

On this theory the positive after-image is not a recurrent image, but the record as given by the retinal rods, delayed in transmission by the low diffusivity characteristic of this kind of vision.

A POLARIZATION FLICKER PHOTOMETER.

By Herbert E. Ives.

ONE of the most essential features of the flicker photometer is entire absence of mechanical flicker, as caused by the dividing edge between the two fields which are alternated. For this reason some means of eliminating this edge has long been desired.

From another standpoint, that of the theoretical treatment of flickering light, it is highly desirable to have an instrument in which the transition from one light to the other occurs according to some simple mathematical relation. The simplest relation is the sine curve, on which basis the theory of the flicker photometer has been handled by the writer and Mr. Kingsbury.[1]

The polarization flicker photometer recently constructed meets both these demands completely. It consists of a double image prism (Rochon or Wollaston prism), combined with a rotating Nicol prism. The double image prism forms two images of each half of the photometer field, one image being polarized in the horizontal, the other in the vertical plane. The horizontally polarized image of one field is superposed on the vertically polarized image of the other. On observing through the rotating Nicol prism, these two fields dissolve one into the other, following exactly the sine curve relation used in the theoretical work quoted.

Measurements have been made with this new photometer on the critical speeds for disappearance of flicker for various ratios of

[1] "The Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1914, p. 708, April, 1916, p. 290.

brightness of the two fields. The results are in complete agreement with the previously developed theory, accurate confirmation of which had not been found possible with the ordinary type of flicker photometer.

MEASUREMENTS OF BRIGHTNESS-DIFFERENCE PERCEPTION AND HUE-DIFFERENCE PERCEPTION BY STEADY AND INTERMITTENT VISION.

By Herbert E. Ives.

In the theory of the flicker photometer as developed by the writer and Mr. Kingsbury [1] there figure two fractions, the brightness discrimination fraction, and the hue discrimination fraction. The former conditions the critical speed when two unequal fields of the same color are alternated, the latter when two equally bright fields of different color are alternated. These fractions are the least fractional parts appreciable by the ultimate receiving apparatus of the eye (presumably the brain), for successive impressions over the same path, and are neither susceptible of direct measurement. They can, however, be solved for from the equations of the theory, provided experimental constants can be obtained for stimuli following the simple sine curve variation of intensity which alone is susceptible of mathematical treatment.

The new polarization flicker photometer (see previous note) provides just such data, and has made possible the determination of the numerical values of these constants, and, what is more important, their relative values as compared to the same quantities for steady observation.

The value of the ultimate brightness discrimination fraction for intermittent light is found to be of the order of magnitude of one-fiftieth of one per cent. The hue discrimination fraction is of course dependent on the size of the color difference worked with. A complete determination of brightness and hue discrimination fractions, both steady and intermittent, for a certain large color difference, shows that the ratio of hue fraction to brightness fraction is about ten times larger for intermittent than for steady vision. *Herein lies the reason for the success of the flicker photometer*, for if these fractions maintained their steady relationship, the flicker photometer would have to be run at such speed, in order to eliminate color flicker, that no sensibility would be left.

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[1] "Theory of the Flicker Photometer," Ives and Kingsbury, Philosophical Magazine, November, 1915, p. 708, April, 1916, p. 290.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, September 6, 1916.)

Hall of The Franklin Institute,
Philadelphia, September 6, 1916.

Mr. Charles E. Bonine *in the Chair.*

The following reports were presented for first reading:

No. 2675.—Sharples Super-Centrifuge.

No. 2676.—Eldred Electric Lamp Leading-in Wire.

The following report was presented for final action:

No. 2635.—Northrup's Electric Furnace and High Temperature Investigations. Elliott Cresson Medal to Dr. Edwin Fitch Northrup, of Princeton, N. J., adopted.

R. B. Owens,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 13, 1916.)

RESIDENT.

Mr. H. M. Elliot, Delong Hook and Eye Company, Station "J," Philadelphia, Pa.

Mr. John Cooper Lynch, General Superintendent of Traffic, The Bell Telephone Company, 1631 Arch St. Philadelphia, Pa.

Dr. Paul Straus, Chemist, Lehigh Ave. and Edgemont St., Philadelphia, Pa.

NON-RESIDENT.

Mr. William H. Crago, Civil Engineer, Room 3525, 120 Broadway, New York City, N. Y.

Dr. Alfred B. Hitchins, Research Chemist, in care of Ansco Company, Binghamton, N. Y.

Mr. Walter G. Roland, Brick Manufacturer, Oaks, Montgomery County, Pa.

Mr. Frederick H. Wagner, Jr., Rogers Ave. and Pimlico Road, Station " E," Baltimore, Md.

Mr. Leo Wallerstein, Chemist, 171 Madison Ave., New York City, N. Y.

Mr. Norman T. Whitaker, Patent Lawyer, 22 Legal Building, Washington, D. C.

NECROLOGY.

Eckley Brinton Coxe, Jr., was born in 1873 and died on September 20, 1916. He was graduated from the University of Pennsylvania in 1893.

Mr. Coxe was greatly interested in archæology and financed several expeditions to Egypt during the past ten years.

He was a member of numerous social organizations and clubs. He was elected to membership in The Franklin Institute on September 13, 1899.

Mr. Lightner Henderson, 1515 Monroe Building, Chicago, Ill.
Mr. Thomas G. Hunter, 134 Poplar Ave., Wayne, Pa.
Mr. Mathias Pfatischer, 314 E. 3rd Ave., Roselle, N. J.

LIBRARY NOTES.

PURCHASES.

FLEMING, J. A.—Elementary Manual of Radiotelegraphy and Radiotelephony. 1916.

International Master Boiler Makers' Association, Proceedings. 1916.

MARTIN, G., SMITH, S., and MILSOM, F.—The Salt and Alkali Industry. 1916.

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NEWELL, F. H., and DRAYER, C. E., ed.—Engineering as a Career. 1916.

SUPINO, GIORGIO.—Land and Marine Diesel Engines. 1915.

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Nebraska State Railway Commission, Eighth Annual Report, 1915. Lincoln, 1915. (From the Commission.)
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Powell, William, Company, Catalogue No. 10. Second Edition. Cincinnati, Ohio, 1911. (From the Company.)
Prest-O-Lite Company, Inc., Instruction Book on Oxy-Acetylene Welding and Cutting, Fourth Edition. Indianapolis, no date. (From the Company.)
Rio De Janeiro Museu Nacional, Archivos, vol. xix. Rio de Janeiro, 1916. (From the Museum.)
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BOOK NOTICES.

Mechanical Technology: Being a Treatise on the Materials and Preparatory Processes of the Mechanical Industries, by G. F. Charnock, M. Inst. C. E., M. Inst. Mech. E., Professor of Engineering, City of Bradford (Eng.) Technical College, 635 pages, illustrations, plates, tables, 8vo. New York, D. Van Nostrand, 1915. Price, $3.00.

This is a comprehensive text-book of 635 pages and 503 excellent illustrations, with complete Index of 13 pages and a list of books of reference.

The author modestly states in his preface: "It is hoped that the present work may form a useful guide for beginners and those with limited time at their disposal, enabling them to acquire some knowledge of the leading features of the work referred to."

A careful examination enables the reviewer to say that this hope is more than realized and the book is worthy of a place in any technical library. Part I covers: Production and Properties of the Chief Materials of Construction, viz.: Iron and Steel, Bessemer and Open Hearth Processes, Regenerative Furnaces, Gas Producers, Structure of Alloys, "Special" or Alloy Steels, Heat Treatment, Non-ferrous Metals, Properties and Uses of the Principal Varieties of Timber, Stone, Leather, Oils, etc., and Methods of Testing.

Part II.—Production of Castings of Iron and Steel, Defects and Remedies, Foundry Mixtures and Analyses, Die Castings, etc.

Part III.—Forging and Stamping. Production of Parts by Rolling, Wire Drawing, Manufacture of Tubes, Extrusion Processes, Manipulation of Sheet Metals by Flanging, Dishing, Drawing, Embossing, Coining, etc.

It is, of course, impossible in a book of this size, covering so many and diverse operations, to give many details that are more or less familiar to daily workers in metals, but, so far from this observation being in the nature of adverse criticism, the reviewer desires to express appreciation of the skill which has been shown throughout in balancing all parts of the work, avoiding skimping of necessary or important features, on the one hand, or redundancy on the other.

Naturally European practise is more thoroughly treated than American methods which differ in some respects, notably in foundry practise.

The paper and type, clearness of half-tone cuts and diagrams, with fine binding of the book, so that it remains open at any page, when laid flat upon a table, are all minor features worthy of commendation.

In a word this work is creditable alike to the author and publisher and will prove useful to the student and practical worker in metals.

A. E. Outerbridge, Jr.

The Science of Musical Sounds, by Dayton Clarence Miller, D.Sc., Professor of Physics, Case School of Applied Science. 286 pages, illustrations, plates, 8vo. New York, The Macmillan Company, 1916. Price, $2.50.

There have been many works on sound since the classical writings of Koenig, Rayleigh, and von Helmholtz, but none of the writers have made so exhaustive a study of sound as applied to music as has Professor Miller.

This work is based upon a series of eight lectures given at the Lowell Institute in 1914 under the title of "Sound Analysis," such changes being made as are required for presenting the subject to a reader instead of to an auditor.

Mathematical physicists, like von Helmholtz and Rayleigh, have found in the simple harmonic motions of the air in sound-waves a rich field for investigation and for the development of the formulæ descriptive of such motion.

Experimental physicists, like Koenig, have been able to apply their manipulative skill to the analysis of the formulæ and to determine their applicability to the characteristics of sound-waves.

It is an interesting fact that the early workers in the analysis of sound-waves expressed the results of their work in curves and their formulæ, and that these were directly applicable to the study of alternating currents of electricity, so that the early workers in the newer science found the principles governing it already investigated and formulated.

In order to make a record of the complicated vibrations that may be included in a musical tone, instruments of extreme delicacy must be used, and Professor Miller possesses that marvellous combination of inventive ability and mechanical skill that is necessary in devising such instruments and in compelling them to perform their function when built.

What is required in the study of sound-waves is an instrument that can respond to minute vibrations of great rapidity and that is capable of magnifying their amplitudes to any required extent.

Such an instrument is Professor Miller's Phonodeik, which responds to 10,000 complete vibrations, or 20,000 swings, per second and is capable of throwing the reflected beam of an arc light either upon a photographic plate for a permanent record, or upon a screen for showing to an audience. The vibrating beam alone gives a single line of light, but by combining with it a uniform progressive motion any wave-form, from the simple sine curve of a tuning-fork to the complicated curves obtained when a group of voices are singing, can be traced. The beauty and striking character of these curves can only be appreciated by seeing them flash across the screen in one of Professor Miller's lectures.

Other instruments of great precision used in the study of sound are the harmonic analyzer and the harmonic synthesizer. These are used in the mechanical proof of Fourier's Theorem, which is to the effect that any curve, having a wave-length l, can always be reproduced by combining the proper number of simple harmonic curves, each having a wave-length that is an aliquot part of l.

Any wave, after having been photographed by the phonodeik, may be analyzed by the harmonic analyzer, and when its component waves are thus found they can be recombined by the harmonic synthesizer and the original wave-form reproduced. An example of the accuracy of the reproduced curve is shown on page 127, where the synthesized curve is drawn over the original curve, thus showing how nearly exact is the reproduction.

Professor Miller's interest in the musical quality of sounds led him to make two flutes, one of silver and one of gold, for the purpose of studying

the difference in the quality of the tone produced. His analyses prove that the "tone from the gold flute is mellower and richer" than that from flutes of other materials, this being due to the existence of a longer and louder series of partial tones. His studies also prove that two organ pipes of the same internal dimensions will differ in pitch, depending upon their material.

Having technical skill, both as a physicist and as a musician, Professor Miller believes that there is a possibility of securing greater artistic effects in the mechanical production of music.

What is needed to secure this result is a closer coördination between the artistic production of musical sounds and their mechanical analysis.

No one with an appreciation of the physical sciences can read this book without interest: to the lover of music it reveals a vision of the intimate relation of music to the physical principles upon which it is based. What Professor Miller thinks of the latter can be seen by quoting his closing sentence, "No other art than music, through any sense, can so transport one's whole consciousness with such exalted and noble emotions."

GEORGE A. HOADLEY.

PUBLICATIONS RECEIVED.

Diseases of Occupation and Vocational Hygiene: Edited by George M. Kober, M.D., LL.D., Washington, D.C., and William C. Hanson, M.D., Belmont, Mass. 918 pages, illustrations. 8vo. Philadelphia, P. Blakiston's Son & Co. Price, $8.00.

United States Bureau of Mines: Bulletin 105. Black damp in mines by G. A. Burrell, I. W. Robertson and G. G. Oberfell. 88 pages, 8vo. Bulletin 116. Methods of sampling delivered coal and specifications for the purchase of coal for the government by George S. Pope. 64 pages, illustrations, plates, 8vo. Monthly statement of coal-mine fatalities in the United States, May and June, 1916. 2 pamphlets, 8vo. Washington, Government Printing Office, 1916.

United States Department of Agriculture: Bulletin No. 373. Brick roads by Vernon M. Peirce, chief of construction, and Charles H. Moorefield, senior highway engineer. 40 pages, illustrations, plates, 8vo. Bulletin No. 379. Dust explosions and fires in grain separators in the Pacific Northwest by David J. Price, engineer in charge of Grain Dust Explosion Investigations, Bureau of Chemistry, and E. B. McCormick, chief, Division of Rural Engineering, office of Public Roads and Rural Engineering. 22 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1916.

CURRENT TOPICS.

Mill Construction. C. E. Paul. (*Engineering Bulletin, National Lumber Manufacturers' Association*, No. 2, May, 1916.)—The term "mill construction" as commonly used is the name given to that type of building construction in which the interior framing and floors are of timber, arranged in heavy, solid masses and flat, smooth surfaces, so as to expose the least number of corners and to avoid concealed spaces which may not be reached readily in case of fire. A broader interpretation of the term includes the meaning given above, and adds the specification that fire shall pass as slowly as possible from one part of the structure to another. This means that each floor shall be separated from all others by incombustible walls or partitions, and by doors or hatchways which will close automatically in case of fire near them. Stairways, belt passages, and elevator shafts are encased or, preferably, located in fireproof towers. Openings in floors for passage of belts, etc., are either avoided or fully protected against passage of fire or water. The proper installation of an approved automatic sprinkler is of great importance. Ceilings in rooms where highly inflammable stocks are kept or where hazardous processes are followed should be protected by the use of fire-retardent material, such as plastering lead on wire lath or expanded metal. The ceiling should follow the lines of the timbers without an air-space between the two surfaces.

The "mill construction" type of building originated in the cotton and woollen mills of New England in the early days of that industry. Instances of buildings of the mill construction type are found in the early part of the nineteenth century, but no great prominence was given to this particular type of structure until the owners of a large number of these mills formed an organization, about the year 1835, for the mutual protection of their property from damage by fire. An instance of the durability of timber in properly built mill construction buildings is shown in the Warner mill in Newburyport, Mass. In this building heavy timber girders 45 feet long and spanning three bays have carried their load since the early fifties without signs of failure, and are said to be in as good condition to-day as when first installed.

Photographic Negatives upon an Opaque Support. Anon. (*Revue Scientifique*, vol. 54, No. 15, August 5, 1916.)—From time to time various efforts have been made to manufacture photographic plates with a support of paper of very uniform texture, with the object of reducing the cost and other objections of the usual glass or celluloid carrier. The insufficient regularity of texture and transparency of paper have so far, however, defeated the efforts of manufacturers to introduce paper for this purpose. A

method of overcoming this objection, proposed by F. Larajolli, consists in making the print, not by transmitted light, but by reflected light. The emulsion is supported upon a fairly heavy white paper, the back of which is coated with an opaque color. Halation is thus entirely avoided, while the white surface constitutes an efficient reflector. These "plates" are mounted and exposed in the camera in the same manner as the "film-pack." Development is controlled in the same manner as that employed with other papers in which the image is produced by the action of a developer. A special apparatus somewhat like the common type of enlarging camera is employed for printing, arranged with a source of illumination like that employed in lanterns for projecting opaque objects. The cost of such paper plates is said to be one-half that of glass plates and from one-third to one-quarter of celluloid films.

Deep Wells That Feel the Sea. ANON. (*U. S. Geological Survey Press Bulletin*, No. 284, August, 1916.)—In their investigation of the underground water resources of the Coastal Plain of Virginia the geologists of the United States Geological Survey have collected data relating to the many hundreds of artesian wells that yield excellent waters in large areas of the coastal region. Particular note has been made of the quantity and quality of the supply afforded by wells that give flows at the surface. The water of most of these wells is admirably adapted to household uses, though that of some of them contains enough mineral salts in solution to make trouble in boilers used for steam production.

The variation in flow exhibited by these wells with the rise and fall of the tide is of peculiar interest, the flow being notably greater at the flood than at the ebb tide. It is the general opinion among well drillers that practically all flowing wells near tidal rivers or inlets from open bays do feel the distant sea, but some of them so slightly that the variation in flow is not noticeable.

The geologist in charge of the ground-water investigations in Virginia states that changes in water level in wells, due to fluctuations in the height of the surface of some neighboring body of water, have been observed all over the world. It is customary to explain these changes by supposing a direct connection between the river, lake or bay, but in many places, as in eastern Virginia, such connection is clearly impossible, owing to the depth of the wells and the nature of the intervening beds, some of them dense, tough marls and clays. These beds, however, though they do not transmit water, nevertheless contain it, and as water is practically incompressible, any variation of level on the river or bay is transmitted to the well through the water-filled gravels, sands, clays and marls. When a porous bed is tapped by a well the water rises to the point of equilibrium and fluctuates as the hand of the ocean varies its pressure on the beds that confine the artesian flow.

Sources of Platinum. ANON. (*Engineering*, vol. cii, No. 2642, August 18, 1916.)—Russia had always been the source from which the bulk of the world's supply of platinum has been obtained. The main output comes from the Ural Mountains. During 1910, 175,720 ounces of crude platinum was secured, while in 1913 the quantity was 250,000 ounces and during 1914 about 241,200 ounces. The actual output is probably much greater, as a considerable quantity is sold without being officially recorded. The metal is found in placer deposits in several districts, of which the most important are: Tcherdin, Perm, North and South Ekaterinberg, and North and South Verkhotom. The output from these sources has been steadily increasing for a number of years. The richer placer deposits have been derived from the prolonged weathering of a variety of olivine which occurs in the Ural Mountains, in a somewhat narrow zone. They occur also along the mountain slopes in the river beds. The average yield is now under an ounce of platinum per ton of gravel; formerly it was more. The workers have now either to exploit poorer placers, or to develop richer ones in more remote situations which are not only more difficult of access but more troublesome to work, Prospecting has been carried on from time to time, but additional deposits are not readily found. Some of the districts have been worked for nearly eighty years. The Northern Urals have not yet been thoroughly explored, but olivine districts are known to occur there. Dredgers and excavators are now employed for working the deposits.

In Colombia, placer deposits have been extensively worked by the Spaniards since the sixteenth century; they contain both gold and platinum in the proportion of 900 per cent. of the former and 10 per cent. of the latter. Formerly only the gold was recovered and the platinum thrown away. The districts in which the bulk of the platinum is found are on the Pacific side of the Andes, in the valleys of the rivers Atrato, Aguendo, and San Juan. Both the platinum and the gold found in the placers have been eroded from veins in the rocks of the mountains, high up the water-shed. The output of crude platinum in Colombia is 15,000 ounces in 1913 and 17,500 ounces in 1914.

Placer mines yielding platinum occur in northern California and in southern Oregon; the metal is found there in minute, thin, flaky particles, and is always associated with black sands. It is also obtained from a copper-platinum-palladium ore, the product of a mine in Wyoming, and from a gold-platinum-palladium mine in Nevada. During 1912 the California output amounted to 603 ounces of crude platinum; for 1913 the combined output of California and Oregon was 483 ounces, and during 1914 it reached 570 ounces. Traces of platinum have also been found in British Columbia, a few miles from the village of Tulameen. The platinum is associated with chromite in mines worked for diamonds. It is also reported that platinum

deposits of considerable extent have been recently discovered in Spain. They are situated in the Ronda Mountains, about forty miles north of Gibraltar. These mountains are said to have the same geological structure as the Ural Mountains, but the formations of the Ronda section are much greater than the Russian. In the Rhine Provinces of Germany deposits have been discovered which may in the future yield a considerable output. Tasmania and New South Wales in 1914 produced 12,480 ounces. In 1913, 200 ounces of platinum were obtained from Borneo, Sumatra, and elsewhere.

Measuring the Pressure of Light. G. D. WEST. (*Proceedings of the Physical Society of London*, vol. xxviii, part v, August 15, 1916.)—The pressure of the radiation emitted by a carbon filament lamp at a distance of a few centimetres is sufficient to cause a microscopically measurable deflection of the end of a strip of gold or aluminum foil suspended in a closed test-tube. By this means the radiation pressure may be measured, and the results may be checked by a comparison with the energy density of the radiation as deduced from the initial rate of rise of temperature of an exposed blackened copper plate. Previous experiments were carried out in atmospheres of air and hydrogen, and at pressures extending from 76 centimetres to one centimetre of mercury. The present experiments deal with pressures from one centimetre of mercury down to the highest exhaustions that could be reached.

As the pressure is lowered certain gas-action effects make their appearance, but, inasmuch as there is no appreciable difference of temperature on the two sides of the strip, the effects are somewhat different from those that occur in the ordinary type of Crookes radiometer. When the surface of the strip is closer to one side of the containing vessel than to the opposite side, a deflection away from the closer side occurs, and the direction of the deflection is independent of the side of the strip upon which radiation falls. With symmetrically placed strip the deflection should be negligibly small. An explanation of these effects is suggested and a special type of radiometer is described. The nature of the residual gas in the tube does not seem to be very important, but it is found that the repulsive force acting on the strip increases with decreasing pressure until a maximum is reached at about 0.002 centimetres of mercury. With a further reduction of pressure a progressive decrease takes place. By symmetrical suspension and by the use of liquid air and charcoal, it is possible to so reduce the gas-action effect that measurements of the pressure of light of reasonable accuracy are again possible. Experiments on the pressure of light may thus be advantageously carried out at the highest vacua obtainable, or at pressures as far above 0.002 centimetre of mercury as convection currents will permit. The latter alternative is easier and leads to more consistent results.

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THE PARTITION OF THE LOAD IN RIVETED JOINTS.*

BY

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INTRODUCTION.

RIVETED joints occur in many types of construction, and it is therefore of considerable practical importance to determine the exact manner in which they act, in order that a rational basis may be given for their design. The subject has attracted the attention of many experimenters, their investigations being mainly directed to a determination of the resistance of joints to rupture and of the frictional resistance to slip.[1] Attempts have also been made to determine the tension in the body of a rivet due to its contraction on cooling,[2] and Frémont has made an exhaustive study of the actual process of riveting and its effects upon the strength of the joint.[3] None of these experiments, however, have indicated very clearly the action of a riveted joint under working loads; *i.e.*, before permanent deformations of the plates or rivets have occurred. Very few attempts have been made either ex-

* Communicated by the author.

[1] A short bibliography of the subject up to the year 1909 is given in a paper by A. N. Talbot and H. F. Moore—"Tests of Nickel-steel Riveted Joints." *University of Illinois Bulletin*, No. 49. See also Preuss, *Zeit. Ver. Deut. Ing.*, 1912, p. 404, and C. Bach and R. Baumann, *Ibid.*, p. 1890.

[2] R. Baumann.

[3] Étude Expérimentale du Rivetage, Paris, 1906.

perimentally to determine or theoretically to estimate the partition of the load among the rivets under working conditions. It is usually assumed, in designing a riveted joint, that the load is equally divided among the rivets. That this cannot be true in joints as usually designed has been generally recognized by writers on bridge design,[4] and illustrated by experiments on the distortion of lath and india-rubber models.[5]

The writer's attention was first directed to the subject by the results of a few readings taken with a Howard gauge on the cover plates of a large riveted splice tested by Prof. H. M. Mackay, of McGill University, for the Quebec Bridge Commission. These appeared to indicate that the rivets in the end rows received by far the greater portion of the load, and suggested to the writer that the actual partition of the load in any joint could be determined by extensometer measurements on the cover plates of the joint. It was first necessary to determine whether or not the strains of the outer surfaces of the cover plates could be used to obtain the mean strains in the cover plates. This was shown to be the case by the experiment given in Part II, §2 of the present paper, and experiments were commenced upon a series of butt joints having a single line of rivets. While making these experiments it occurred to the writer that the results might be interpreted and the partition of load worked out theoretically by means of the Principle of Least Work. This proved to be so, and further experiments verified the theory in every particular.

The present paper is divided into two parts. Part I shows how, by means of the Principle of Least Work, a series of equations may be obtained, giving the load carried by each rivet in any form of riveted joint in terms of a quantity K, which, if the rivets are in shear, depends upon the manner in which work is stored in the rivets; or, if they act by frictional hold on the plates, depends upon the work stored in the parts of the plates thus held. Part II gives the results of a series of experiments upon different forms of joints having a single line of rivets and loaded in tension, which confirm and illustrate the theory and show how the quantity K may be determined.

[4] See, for example, Burr, "Elasticity and Resistance of the Materials of Engineering," p. 700; Johnson, Bryan and Turneaure, "Framed Structures, part iii; Shaper, Eiserne Brücken.

[5] C. R. Young, *Trans. Can. Soc. C. Eng.*, 1906, part ii, p. 257.

It is felt that much of the usefulness of the theory given depends upon whether the rivets in a joint are in shear or whether they act by holding the plates together by friction. The later experiments on the slip[6] of rivets seem to show that at working loads the latter is the case, and the results of the experiments described in the present paper seem to bear this out. The writer has in hand experiments which he hopes will give definite information on the subject.

NOTE.—In all that follows, a *row* of rivets means a number of rivets arranged in a straight line perpendicular to the axis of load; and a *line* of rivets means a number of rivets arranged in a straight line parallel to the axis of load.

PART I.—THEORETICAL.

§1. *General Method of Analysis.*

A riveted joint may be considered as a statically indeterminate system in which, under the action of external forces, work is stored in the plates and the rivets. It follows, from the Principle of Least Work, that the stresses will be distributed in the different parts of the system in such a way that the elastic work stored is a minimum. In any actual riveted joint the distribution of stress in the plates is more or less complicated,[7] but a close approximation to the forces taken by the rivets may be obtained by assuming the stress to be uniform between any two rows of rivets. The modifying effect of a variable distribution will be considered later (§3). The work stored in the rivets themselves, if they are in shear, or in the parts of the plates immediately surrounding the rivets, if the latter act by holding the plates together, may be taken as kX^2 where X is the load on the rivet and k is a constant, no assumption being made as to the manner in which this work is stored. On the above basis a series of equations may be obtained for any given joint, giving the load taken by each rivet in terms of k.

§2. *The Double-cover Butt Joint with a Single Line of Rivets.*

The simplest case is that of a double-cover butt joint having covers and plates of uniform width, the two cover plates having

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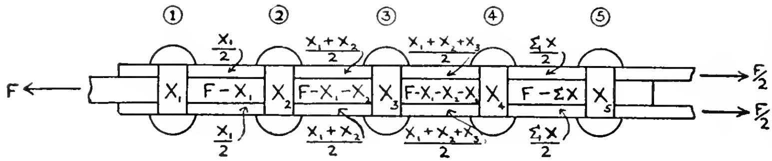
[6] See Preuss, *loc. cit.*

[7] See a paper by Prof. E. G. Coker, *Trans. Inst. Naval Arch.* (England), 1913.

each the same area of cross-section, and the connection being made by a single line of rivets of uniform diameter and pitch (Fig. 1).

FIG. 1.



Let a_p represent the cross-sectional area of the middle plate,
a_c represent the cross-sectional area of each cover plate,
l represent the pitch of the rivets,
n represent the number of rivets on each side of the junction of the main plates,
F represent the load, tensile or compressive, carried by the joint,
and X_1 represent the load carried by the 1st rivet, X_2, that carried by the second rivet, etc.

Then between the first and second rivets the load carried by the main plate is $F - X_1$, and the load carried by each cover plate is $\frac{X_1}{2}$; between the second and third rivets the load carried by the main plate is $F - X_1 - X_2$, and by each cover plate is $\frac{X_1+X_2}{2}$; and between the $(n-1)^{th}$ and n^{th} rivet the load carried by the main plate is $F - \sum_1^{n-1} X$ and by each cover plate is $\frac{\sum_1^{n-1} X}{2}$, where $\sum_1^{n-1} X = X_1 + X_2 + \ldots\ldots X_{n-1}$. The distribution of the load for five rivets is shown in Fig. 1, which represents one-half of the joint.

Now assuming that the stress in any portion of a plate between two rivets is uniformly distributed (see §1), the work stored in this portion, if the load carried by it is P, is $\frac{P^2 l}{2aE}$ where a is the cross-sectional area, l the pitch of the rivets,[8] and E is Young's Modulus for the material of the plate. It will be assumed that E is the same for both cover and middle plates.[9] The work stored in the rivets will be assumed to be of the form kX^2, as described above.

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[8] l should really be taken a little less than the pitch of the rivets in order to allow for the portion of the plate cut away for the rivet hole.

[9] See § 3.

Then, if W represents the total work stored in one-half of the joint,

$$2EW=\frac{l}{a_p}\left[(F-X_1)^2+(F-X_1-X_2)^2+(F-X_1-X_2-X_3)^2+\ldots\ldots+(F-\Sigma X)^2\right]$$

$$+\frac{2l}{a_c}\left[\left(\frac{X_1}{2}\right)^2+\left(\frac{X_1+X_2}{2}\right)^2+\left(\frac{X_1+X_2+X_3}{2}\right)^2+\ldots\ldots+\left(\frac{\Sigma X}{2}\right)^2\right]$$

$$+k\left[X_1^2+X_2^2+X_3^2+\ldots\ldots\ldots+(F-\Sigma X)^2,\quad\right],\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where $\Sigma X=X_1+X_2+X_3+\ldots\ldots\ldots+X_{n-1}$.

In accordance with the Principle of Least Work, the forces X_1, X_2, etc., in the above will take the values which will make W a minimum.

Thus

$$\frac{\partial W}{\partial X_1}=0,\ \frac{\partial W}{\partial X_2}=0,\ \frac{\partial W}{\partial X_3}=0\ \ldots\ldots\ \frac{\partial W}{\partial X_{n-1}}=0$$

But $$\frac{\partial W}{\partial X_1}=-\frac{2l}{a_p}\left[(F-X_1)+(F-X_1-X_2)+\ldots\ldots\ldots+(F-\Sigma X)\right]$$

$$+\frac{l}{a_c}\left[X_1+(X_1+X_2)+\ldots\ldots\ldots+\Sigma X\right]$$

$$+2k\left[X_1-(F-\Sigma X)\right].$$

Thus, equating this to zero and dividing through by $\frac{a_c}{l}$,

$$\left[(n-1)\left(1+\frac{2a_c}{a_p}\right)+\frac{4ka_c}{l}\right]X_1+\left[(n-2)\left(1+\frac{2a_c}{a_p}\right)+\frac{2ka_c}{l}\right]X_2$$

$$+\ldots\ldots\ldots+\left[\left(1+\frac{2a_c}{a_p}\right)+\frac{2ka_c}{l}\right]X_{n-1}=\left[(n-1)\frac{2a_c}{a_p}+\frac{2ka_c}{l}\right]F.$$

Writing $C=1+\frac{2a_c}{a_p}$ and $K=\frac{2ka_c}{l}$, and taking $F=1$ for convenience,

$$[(n-1)C+2K]X_1+[(n-2)C+K]X_2+\ldots\ldots+[C+K]X_{n-1}=(n-1)C+K$$

Differentiation with respect to X_2, X_3 etc., leads to the equations

$$[(n-2)C+K]X_1+[(n-2)C+2K]X_2+[(n-3)C+K]X_3+\ldots\ldots\ldots+[C+K]X_{n-1}$$
$$=(n-2)C+K,$$

$$[(n-3)C+K]X_1+[(n-3)C+K]X_2+[(n-3)C+2K]X_3+\ldots\ldots\ldots+[C+K]X_{n-1}$$
$$=(n-3)C+K,$$

$$\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$

$$[C+K]X_1+[C+K]X_2+[C+K]K_3+\ldots\ldots+[C+2K]X_{n-1}=C+K.$$

Thus a set of $(n-1)$ linear simultaneous equations has been established, from which $X_1, X_2 \ldots X_{n-1}$ may be found, while $X_n = 1 - \Sigma X$. For the sake of brevity in what follows, the above and all similar equations will be written in the abbreviated form

$$\left| \begin{array}{c|c|c|c|c||c} (n-1)C+2K & (n-2)C+K & (n-3)C+K & \ldots\ldots & C+K & (n-1)C+K \\ (n-2)C+K & (n-2)C+2K & (n-3)C+K & \ldots\ldots & C+K & (n-2)C+K \\ (n-3)C+K & (n-3)C+K & (n-3)C+2K & \ldots\ldots & C+K & (n-3)C+K \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ C+K & C+K & C+K & \ldots\ldots & C+2K & C+K \end{array} \right| \quad (2)$$

It will be noticed that the quantities C and K in the above have no dimensions, but are simply numbers. C is determined from the ratio of thickness of cover plate to thickness of main plate. Thus, if each of the cover plates has half the thickness of the middle plate $C = 2$, if each cover plate is of the same thickness as the middle plate $C = 3$, etc. K must be determined by experiment in the absence of an exact theoretical estimate of the work stored in a rivet carrying a given load. This matter will be discussed later.

It would serve no useful purpose to give a general solution of the above equations for any number of rivets, as the equations may be solved easily for any particular case and the results are similar in form, whatever n may be. In the experiments described later the number of rivets on each side of the junction was usually five, so that the solution for $n = 5$ will be considered in detail.

In this case equations (2) reduce to

$$\left| \begin{array}{c|c|c|c||c} 4C+2K & 3C+K & 2C+K & C+K & 4(C-1)+K \\ 3C+K & 3C+2K & 2C+K & C+K & 3(C-1)+K \\ 2C+K & 2C+K & 2C+2K & C+K & 2(C-1)+K \\ C+K & C+K & C+K & C+2K & (C-1)+K \end{array} \right| \ldots\ldots\ldots\ldots (3)$$

Subtracting the second equation from the first, and the third from the second,

$$KX_2 = (C+K)X_1 - (C-1) \ldots\ldots\ldots\ldots (4)$$

$$KX_3 = CX_1 + (C+1)X_2 - (C-1) \ldots\ldots\ldots\ldots (5)$$

Eliminating X_4 from the third and fourth equations and substituting X_2 and X_3 from the above,

$$X_1 = \frac{K^4 + (C-1)10K^3 + (C^2-C)15K^2 + (C^3-C^2)7K + (C^4-C^3)}{5K^4 + 20CK^3 + 21C^2K^2 + 8C^3K + C^4} \ldots\ldots (6)$$

This expression may be used to find X_1 for any particular values of C and K. X_2 and X_3 may then be determined from equations (4) and (5), X_4 from the last equation of (3), and $X_5 = 1 - \Sigma X$.

It may readily be seen from equation (6) that the assumption ordinarily made in designing riveted joints, *i.e.*, that all the rivets take an equal proportion of the load, would only be true if $K = \infty$, in which case $X_1 = X_2 = X_3 = X_4 = X_5 = 1/5$. But this would mean that the rivets were quite flexible and offered no resistance to distortion, which would be a practical impossibility. Thus, in any joint of the type considered in this section, the load must be unequally distributed among the rivets.

If the rivets were absolutely rigid, *i.e.*, suffered no distortion when the joint was loaded, K would be equal to zero and

$$X_1 = \frac{C-1}{C},$$

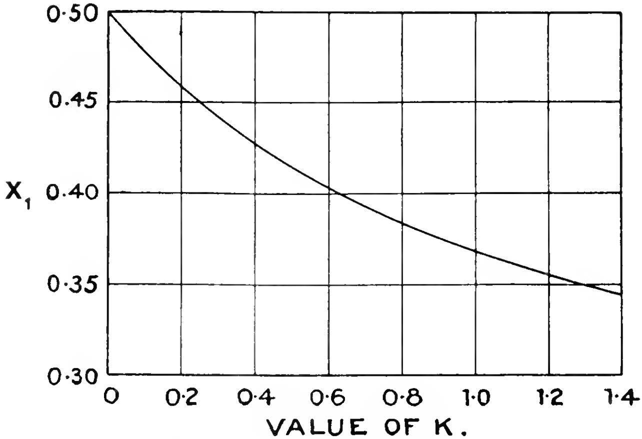
while $X_2 = X_3 = X_4 = 0$ and $X_5 = \frac{1}{C}$. Thus the first and last rivets would carry all the load.

If C were equal to 2, *i.e.*, if the cover plates were of the correct thickness, each one-half of the thickness of the main plate, these rivets would each take one-half of the load; if the covers were each equal in thickness to the main plate, the first rivet would carry two-thirds of the load and the last one-third; and if the covers were only one-quarter the thickness of the main plate, the first rivet would carry one-third of the load and the last two-thirds.

Actually the rivets are neither infinitely flexible nor infinitely rigid, but are elastic, and K has some finite value. Fig. 2 shows the value of X_1 for all values of K between 0 and 1.4 when there are five rivets. This curve will be used later in discussing the experimental results. The greater the value of K the more nearly uniform are the loads carried by the rivets, but, from the actual experimental values found from the specimens tested, it would appear that in most practical cases the two end rivets carry by far the greater part of the total load. The greatest experimental value of K was 1.30 for ½-inch rivets at about one and a half times the working load. At the working load it was approximately equal to unity. In order to simplify the present discussion this value will be taken in most of the illustrative cases.

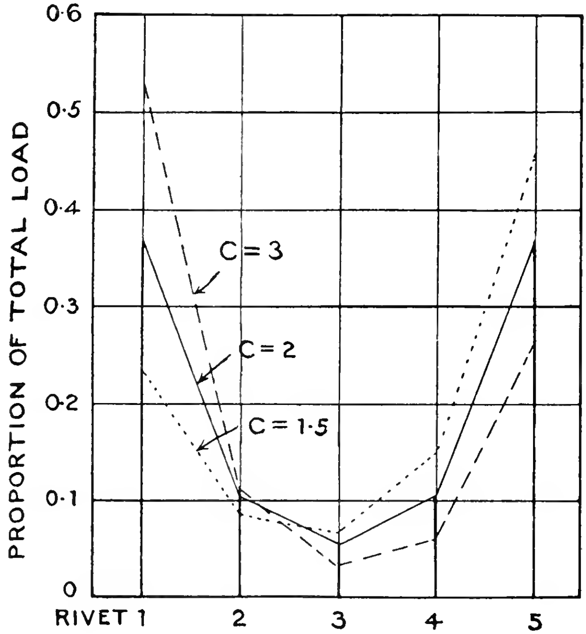
The proportion of the load carried by each rivet when $K = 1$ is tabulated in Table I for three values of C, while Fig. 3 shows the results graphically. These three examples will serve to show the

FIG. 2.



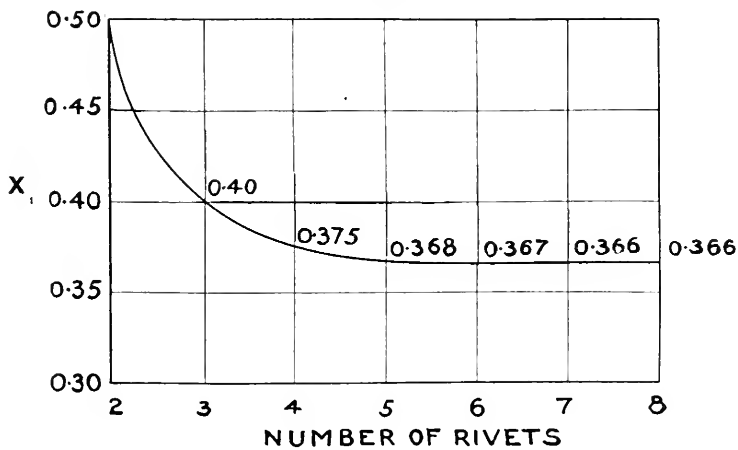
Curve connecting X_1 and K for five rivets.

FIG. 3.



general manner of distribution in most practical cases. In each case the end rivets take the greater part of the load, carrying 0.695, 0.736, and 0.793 of the total load when $C = 1.5$, 2, and 3.0 respectively. In no case does the middle rivet carry more than a very small fraction of the total load. It will be noticed that the distribution is symmetrical when the cover plates are of the correct thickness, *i.e.*, when $C = 2$. This is so no matter what value K may have, and, by taking account of this, the equations may be simplified by putting $X_2 = X_4$, thus reducing their number by one equation. When there is a large number of rivets, this shortens the solution considerably. For example, if $n = 10$, the number of

FIG. 4.



equations may be reduced from 9 to 6. When the thickness of each of the cover plates is more than one-half of the thickness of the main plate, the first rivet receives more than the last, as shown by the diagram for $C = 3$. On the other hand, when C is less than 2 this condition is reversed, the last rivet receiving more than the first.

Fig. 4 shows the proportion of the total load taken by the first rivet for $C = 2$, $K = 1$ for joints having 1–8 rivets on each side of the junction. It will be noticed that the curve becomes practically horizontal when the number 5 is reached, so that no matter how many more rivets may be added, the two end rivets

get practically the same proportion of the total load as with five rivets. This means that as the number of rivets increases each of the other rivets receives a less and less proportion of the load, and those near to the middle of the joint are practically idle.

§3. *Effect of Factors Neglected in the Above Analysis.*

(*a*) Effect of Non-uniform Distribution of Stress in the Plates.

It was assumed, in estimating the work stored in the plates, that the stress is distributed uniformly between any pair of rivets. A glance at Fig. 9, page 583, will show that this is not so, the stress varying from a minimum along the centre line of the rivets to a maximum at the edges of the plate. In addition to this variation in the free portions of the plates between the rivets there must be considerable local variations of stress round the rivet holes.[10] It will be necessary to consider the effect of this non-uniform distribution on the equations (2) given above.

The effect will be equivalent to multiplying every term of the form $\frac{P^2 l}{2aE}$ in the expression for the work stored, equation (1), by some coefficient α which will depend upon the manner of distribution of stress in the portion considered. If the variation of stress were the same in all portions of all the plates, *i.e.*, if α were the same for all the terms, it may easily be seen that the only effect of this would be to multiply K by the coefficient $\frac{1}{\alpha}$. If, however, α were different in different parts of the plates, as will usually be the case, the terms of equations (2) would be affected differently and there would be a modification of the distribution of load between the rivets. Fortunately the coefficient α cannot be very different from unity, as the following analysis will show.

Suppose that the stress in a portion of the cover plate between two rivets varies uniformly from f_1 at the centre line to f_2 at the edges. This is not far from the actual manner of distribution as shown in Fig. 9, page 583. Let the length of the portion considered be l, the breadth $2b$, and the thickness t, a_c being $2\ bt$. Then the mean stress in the plate is $\frac{f_1+f_2}{2}$. If this were uniformly

[10] This variation has been examined for a more or less analogous case by E. G. Coker, using his polarized light method. See *Trans. I. N. A.*, 1913.

distributed, as assumed in the analysis of §2, the work stored in the portion considered would be

$$W_1=(f_1+f_2)^2\frac{btl}{4E}$$

The actual work stored, however, is

$$W_2=2\int_o^b\left\{f_1+\frac{f_2-f_1}{b}\cdot x\right\}^2\cdot\frac{tl}{2E}\cdot dx.$$

$$=\frac{btl}{3E}\left\{f_1^2+f_1f_2+f_2^2\right\}$$

The ratio

$$r=\frac{W_2}{W_1}=\frac{4}{3}\cdot\frac{f_1^2+f_1f_2+f_2^2}{(f_1+f_2)^2}=\frac{4}{3}\left\{1-\frac{f_1f_2}{(f_1+f_2)^2}\right\}. \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Now the maximum variation of stress observed in the experiments was about 20 per cent.; *i.e.*, $\frac{f_2}{f_1}=\frac{5}{4}\cdot$ For this variation $r=\frac{4}{3}\left\{1-\frac{20}{81}\right\}=1.004$; *i.e.*, the work stored is about 0.4 per cent. greater than it would be if the stress were uniformly distributed. A longitudinal variation of stress of the same amount would give the same result. Thus no appreciable error is caused by neglecting this factor. The probably intense local variations of stress in the immediate neighborhood of the rivets are not easy to estimate, but they extend over a small area only and are probably similar in all the plates, so that they will be included in the experimental estimates of K, as will also be the error due to disregarding the parts of the plate cut away for the rivet holes in estimating the volume of the plate between a pair of rivets. Neither of these is likely to have any great effect upon the value of K.

(*b*) Effect of Unequal Partition of the Load Between the two Cover Plates.

It was assumed, in the analysis of §2, that the cover plates each received one-half of the load transmitted to them by the rivets. This was not so in most of the experiments described in Part II.

Suppose that one cover plate takes $\frac{1}{s}$ of the load, then the other takes $1 - \frac{1}{s}$ and equation (1) becomes

$$2EW = \frac{l}{a_p}\left[(F-X_1)^2+\ldots\ldots\right]+\frac{l}{s^2a_c}\left[X_1^2+(X_1+X_2)^2+\ldots\ldots+(\Sigma X)^2\right]$$
$$+\frac{(s-1)^2}{s^2}\left[X_1^2+(X_1+X_2)^2+\ldots\ldots(\Sigma X)^2\right]+k\left[k_1^2+X_2^2+\ldots\ldots+(F-\Sigma X)^2\right]$$

TABLE I.

C	X_1	X_2	X_3	X_4	X_5
1½	0.235	0.086	0.068	0.151	0.460
2	0.368	0.105	0.054	0.105	0.368
3	0.528	0.112	0.034	0.061	0.265

On differentiating this with respect to X_1, X_2, etc., and forming the equations as before, it will be found that the equations take exactly the same form as in the last section if C be written for

$$\frac{2a_c}{a_p}+2\left(1-\frac{2}{s}+\frac{2}{s^2}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

instead of for $\frac{2a_c}{a_p}+1$, as in equations (2).

Thus the effect of the non-equipartition of the load is equivalent to a change of C.

Suppose, for example, that $\frac{1}{s}=0.6$, the cover plates being of the correct thickness for which C would be equal to 2 if the load were equally divided. Then

$$C=2[0.5+1-1.2+0.72]$$
$$=2.04.$$

If $K=1$, the effect of this change of C may be seen from the annexed table. The load taken by the first rivet is increased about 2.44 per cent., and the load taken by the last rivet is decreased 1.36 per cent.

In practical cases, owing to want of straightness of the plates, etc., it will often happen that s is not the same throughout. This

could be allowed for in a similar manner, but, of course, no general rule can be given. The effect is not likely to be great in any case, as may be seen from the above. It should, however, be allowed for in reducing experimental data to obtain exact values of K.

TABLE II.

C	X_1	X_2	X_3	X_4	X_5
2.00	0.368	0.105	0.054	0.105	0.368
2.04	0.377	0.106	0.052	0.102	0.363

(c) Effect of the Main Plate and Cover Plates Having Different Moduli of Elasticity.

It often happens that the cover plates, being thinner than the main plates, have a greater modulus of elasticity. Let E_c be the modulus of the cover plates, E_p that of the main plate, and let the ratio $\frac{E_c}{E_p} = r$. It may be shown from equation (1) that the effect of r being different from unity is to change C from $1 + \frac{2a_c}{a_p}$ to

$$C = 1 + \frac{2a_c}{a_p} \cdot r \quad \text{(9)}$$

For example, if $E_c = 31 \times 10^6$ pounds per square inch and $E_r = 29 \times 10^6$ pounds per square inch, $r = \frac{31}{29}$, and, if the covers are each of half the thickness of the main plate,

$$C = 2.069.$$

The effect is thus similar to that discussed in (b).

Thus factors (b) and (c) both tend to increase the load taken by the first rivet and decrease that taken by the last.

§4. *Joint in Which the Middle Plate is of Variable Width, as in the Connection of Members to a Gusset Plate.*

In this section an analysis will be made of a joint of the type shown in Fig. 6a, page 573, which consists of two similar plates of uniform width attached one on each side of a plate of variable

width. In such a connection there will be no bending of the plates if the load carried by each of the outer plates is the same.

The analysis will be given for five rivets, but may readily be extended to any number. The same assumptions will be made as in §2.

Let a_c represent the cross-sectional areas of the outer plates, a_1, a_2, a_3 and a_4 . . the cross-sectional areas of the gusset plate mid-way between rivets 1 and 2, between rivets 2 and 3, etc., respectively. Then, assuming uniform distribution of stress in the plates between each pair of rivets, the work stored in each outer plate between any pair of rivets is $\frac{P^2l}{2a_cE}$, as in §2, but the work stored in the middle plate will take a more complicated form because of the variable width. Consider the portion of the middle plate between rivets 1 and 2. Then, if the load on this portion is P,

$$2EW = \Sigma \frac{P^2dx}{A}$$

$$= \frac{P^2}{t} \int_0^l \frac{dx}{b_2 + \frac{b_1 - b_2}{2}.x.}$$

$$= \frac{P^2l}{(b_1 - b_2)t} \cdot \log_e \frac{b_1}{b_2},$$

where b_1 and b_2 are the widths of the plate at rivet 1 and rivet 2 respectively and t is its thickness. If the plate were of uniform width, $\frac{b_1+b_2}{2}$,

$$2EW_1 = \frac{2P^2l}{b_1+b_2}$$

Thus the ratio

$$\eta_1 = \frac{W}{W_1} = \frac{b_1+b_2}{2(b_1-b_2)} \log_e \frac{b_1}{b_2} \quad \text{(10)}$$

Thus the work stored in the portions of the middle plate may be expressed as $\eta_1 \frac{P_1^2l}{2a_1E}$, $\eta_2 \frac{P_2^2l}{2a_2E}$, etc., where η is a coefficient calculated from equation (10). On substituting these values in the work equation (equation (1), § 2), the first term becomes

$$l\left[\frac{\eta_1}{a_1}(F-X_1)^2 + \frac{\eta_2}{a_2}(F-X_1-X_2)^2 + \ldots\ldots + \frac{\eta_4}{a_4}(F-\Sigma X)^2\right]$$

the other terms remaining as before. The method of §2 then leads to the equations

$$\left|\begin{array}{cccc|c}
4+2a_c\sum_1^4\frac{\eta}{a}+2K & 3+2a_c\sum_2^4\frac{\eta}{a}+K & 2+2a_c\sum_3^4\frac{\eta}{a}+K & 1+2a_c\sum_4^4\frac{\eta}{a}+K & 2a_c\sum_1^4\frac{\eta}{a}+K \\
3+2a_c\sum_2^4\frac{\eta}{a}+K & 3+2a_c\sum_2^4\frac{\eta}{a}+2K & 2+2a_c\sum_3^4\frac{\eta}{a}+K & 1+2a_c\sum_4^4\frac{\eta}{a}+K & 2a_c\sum_2^4\frac{\eta}{a}+K \\
2+2a_c\sum_3^4\frac{\eta}{a}+K & 2+2a_c\sum_3^4\frac{\eta}{a}+K & 2+2a_c\sum_3^4\frac{\eta}{a}+2K & 1+2a_c\sum_4^4\frac{\eta}{a}+K & 2a_c\sum_3^4\frac{\eta}{a}+K \\
1+2a_c\sum_4^4\frac{\eta}{a}+K & 1+2a_c\sum_4^4\frac{\eta}{a}+K & 1+2a_c\sum_4^4\frac{\eta}{a}+K & 1+2a_c\sum_4^4\frac{\eta}{a}+2K & 2a_c\sum_4^4\frac{\eta}{a}+K
\end{array}\right|$$

where

$$\sum_1^4\frac{\eta}{a}=\frac{\eta_1}{a_1}+\frac{\eta_2}{a_2}+\frac{\eta_3}{a_3}+\frac{\eta_4}{a_4}$$

$$\sum_4^4\frac{\eta}{a}=\frac{\eta_4}{a_4},\quad \text{etc.}$$

or writing

$$\alpha=4+2a_c\sum_1^4\frac{\eta}{a}+K,$$

$$\beta=3+2a_c\sum_2^4\frac{\eta}{a}+K,$$

$$\gamma=2+2a_c\sum_3^4\frac{\eta}{a}+K,$$

$$\delta=1+2a_c\sum_4^4\frac{\eta}{a}+K,$$

the equations become

$$\left|\begin{array}{cccc|c}
\alpha+K & \beta & \gamma & \delta & \alpha-4 \\
\beta & \beta+K & \gamma & \delta & \beta-3 \\
\gamma & \gamma & \gamma+K & \delta & \gamma-2 \\
\delta & \delta & \delta & \delta+K & \delta-1
\end{array}\right| \qquad (11)$$

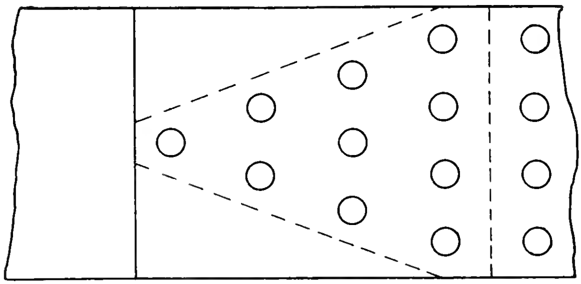
These equations are similar in form to those obtained in §2 and the same method of solution may be used. An example is given in Part II, §5.

§5. *Splices with Various Groupings of Rivets.*

The joints considered in the former sections contained a single line of rivets only. When a large number of rivets is required for a connection, it is usual to group the rivets in several rows, a different number in each row, as, for example, in the

splice shown in Fig. 5, which contains one rivet in the first row, two in the second, three in the third, etc. The distribution of the load between the various rivets of such a splice may be calculated by a similar method to that used in the cases considered above if the additional assumption is made that all the rivets in each row take the same load, which is probably nearly true in most

FIG. 5.



cases, although experimental data are not yet available on this point.

Let η_1 be the number of rivets in the first row, η_2 the number in the second row, etc., and, for simplicity, consider that there are only five rows on each side of the junction. Let X_1 be the total load taken by the first row of rivets, X_2 that taken by the second row, etc. Then each rivet of the first row will take the load $\frac{X_1}{n_1}$, each rivet of the second row $\frac{X_2}{n_2}$, etc. The work equation will be

$$2EW = \frac{l}{a_p}\left[(F-X_1)^2+(F-X_1-X_2)^2+\ldots\ldots+(F-\Sigma X)^2\right]$$
$$+\frac{2l}{a_c}\left[\left(\frac{X_1}{2}\right)^2+\left(\frac{X_1+X_2}{2}\right)^2+\ldots\ldots+\left(\frac{\Sigma X}{2}\right)^2\right]$$
$$+k\left[n_1\left(\frac{X_1}{n_1}\right)^2+n_2\left(\frac{X_2}{n_2}\right)^2+\ldots\ldots+n_5\left(\frac{F-\Sigma X}{n_5}\right)^2\right]\ldots\ldots\ldots(12)$$

This leads to the equations

$$\left|\begin{array}{cccc|c}
4C+K\left(\frac{1}{n_1}+\frac{1}{n_5}\right) & 3C+\frac{K}{n_5} & 2C+\frac{K}{n_5} & C+\frac{K}{n^5} & 4(C-1)+\frac{K}{n_5} \\
3C+\frac{K}{n_5} & 3C+K\left(\frac{1}{n_2}+\frac{1}{n_5}\right) & 2C+\frac{K}{n_5} & C+\frac{K}{n_5} & 3(C-1)+\frac{K}{n_5} \\
2C+\frac{K}{n_5} & 2C+\frac{K}{n_5} & 2C+K\left(\frac{1}{n_3}+\frac{1}{n_5}\right) & C+\frac{K}{n_5} & 2(C-1)+\frac{K}{n_5} \\
C+\frac{K}{n_5} & C+\frac{K}{n_5} & C+\frac{K}{n_5} & C+K\left(\frac{1}{n_4}+\frac{1}{n_5}\right) & (C-1)+\frac{K}{n_5}
\end{array}\right|$$

(13)

C and K having the same meanings as in §2. The method of solution is the same as for the equations of the preceding sections. Similar equations for any number of rows of rivets may be built up from a consideration of the above.

It will be interesting to consider one or two numerical examples in order to illustrate the method and to see how far the ordinary assumption of design—that each rivet carries an equal proportion of the load,—is justified. Take first the splice shown in Fig. 5, having four rows of rivets containing 1, 2, 3 and 4 rivets respectively. Let $C=2, K=1$ and $F=1$. Equations (13) reduce to

$$\left|\begin{array}{c|cc||c} 7.25 & 4.25 & 2.25 & 3.25 \\ 4.25 & 4.75 & 2.25 & 2.25 \\ 2.25 & 2.25 & 2.583 & 1.25 \end{array}\right|$$

TABLE III.

Specimen	Diameter of rivets	Thickness of middle plate	Thickness of each outer plate
A	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{5}{16}''$
B	$\frac{3}{4}''$	$\frac{1}{2}''$	$\frac{1}{4}''$
C	$\frac{7}{8}''$	$\frac{1}{2}''$	$\frac{1}{4}''$
D	$\frac{3}{4}''$	$\frac{1}{4}''$	$\frac{3}{8}''$
E	$\frac{3}{4}''$	$\frac{1}{4}''$	$\frac{1}{4}''$
F and F′	$\frac{3}{4}''$	$\frac{1}{4}''$	$\frac{1}{4}''$

These give

$$X_1=0.339,\quad X_2=0.034,\quad X_3=0.159,\quad \text{and}\quad X_4=0.468.$$

These are the total loads carried by each row. Thus

each rivet in the first row takes 0.339,
each rivet in the second row takes 0.017,
each rivet in the third row takes 0.053,
each rivet in the fourth row takes 0.117.

Thus more than one-third of the total force is carried by the first rivet, while the middle rows take very little load. The load carried by the first rivet is so great that it will probably fail. If

this happens, or if the first rivet is removed, the values of X will become

$$X_2=0.416,\quad X_3=0.121,\quad X_4=0.463.$$

and

each rivet of the second row will take 0.208,
each rivet of the third row will take 0.040,
each rivet of the fourth row will take 0.116.

Thus the distribution is somewhat improved, but if the splice is in tension, the main plate is weakened by two rivet holes.

If the second row of rivets be removed,

$$X_3=0.441,\quad X_4=0.559.$$

Thus

each rivet in the third row takes 0.147,
each rivet in the fourth row takes 0.140,

and the distribution is much more uniform.

Usually in a splice of the type considered the cover plates are cut away as shown by the dotted lines in Fig. 5. This will alter the distribution of stress. Suppose, for example, that the widths of the cover plates at the first, second, third, and fourth rows of rivets are in the ratio 1 : 2 : 3 : 4. The equations will take the form

$$\left|\begin{array}{ccc|c}
3+a_c\sum_1^3\frac{\eta}{a}+K\left(\frac{1}{n_1}+\frac{1}{n_4}\right) & 2+a_c\sum_2^3\frac{\eta}{a}+\frac{K}{n_4} & 1+a_c\sum_3^3\frac{\eta}{a}+\frac{K}{n_4} & 3+\frac{K}{n_4} \\
2+a_c\sum_2^3\frac{\eta}{a}+\frac{K}{n_4} & 2+a_c\sum_2^3\frac{\eta}{a}+K\left(\frac{1}{n_2}+\frac{1}{n_4}\right) & 1+a_c\sum_3^3\frac{\eta}{a}+\frac{K}{n_4} & 2+\frac{K}{n_4} \\
1+a_c\sum_3^3\frac{\eta}{a}+\frac{K}{n_4} & 1+a_c\sum_3^3\frac{\eta}{a}+\frac{K}{n_4} & 1+a_c\sum_3^3\frac{\eta}{a}+K\left(\frac{1}{n_3}+\frac{1}{n_4}\right) & 1+\frac{K}{n_4}
\end{array}\right| \tag{14}$$

where a_c is the area of cross-section of the cover plates when of the same width as the middle plate.

Substituting numerical values.

$$\begin{aligned}
\eta_1 &= \tfrac{3}{2}\log_\epsilon 2 &&= 1.0397,\\
\eta_2 &= \tfrac{5}{2}\log_\epsilon 1.5 &&= 1.0136,\\
\eta_3 &= \tfrac{7}{2}\log_\epsilon \tfrac{4}{3} &&= 1.007,
\end{aligned}$$

and the equations become

$$\left|\begin{array}{c|c|c|c}
9.795 & 5.022 & 2.401 & 3.25 \\
5.022 & 5.522 & 2.401 & 2.25 \\
2.401 & 2.401 & 2.734 & 1.25
\end{array}\right|$$

From these

$$X_1=0.225,\ X_2=0.145,\ X_3=0.132,\ X_4=0.498.$$

Thus

each rivet in the first row takes 0.225,
each rivet in the second row takes 0.072,
each rivet in the third row takes 0.044,
each rivet in the fourth row takes 0.125.

Thus shaping the cover plate decreases the load taken by the first rivet. If the first rivet be omitted

$$X_2=0.338,\ X_3=0.160,\ X_4=0.502$$

and

each rivet in the second row takes 0.169,
each rivet in the third row takes 0.053,
each rivet in the fourth row takes 0.125.

If the second row be also omitted

$$X_3=0.458,\ X_4=0.542$$

and

each rivet of the third row takes 0.153,
each rivet of the third row takes 0.135.

These illustrations are sufficient to show how the method may be used to determine the partition of load in any form of splice. The problem of the best arrangements of rivets in splices will be deferred until further experiments have been made.

§6. *Joints Having Rivets of Different Sizes or for Which the Values of K are Different.*

Consider a joint having a single line of rivets, five on each side of the junction. Let the values of K for the rivets be K_1, K_2, K_3, K_4 and K_5 for the first, second, third, fourth, and fifth rivets respectively. Then the work equation will be similar to that given in §2, equation (1), but the last term will be

$$K_1X_1^2+K_2X_2^2+\ \ldots\ldots\ +K_5(F-\Sigma X)^2.$$

Thus the equations for this case will be

$$\left|\begin{array}{l} 4C+K_{15}+K_5 \\ 3C+K_5 \\ 2C+K_5 \\ \ \ C+K_5 \end{array}\right| \begin{array}{l} 3C+K_5 \\ 3C+K_2+K_5 \\ 2C+K_5 \\ \ \ C+K_5 \end{array} \left|\begin{array}{l} 2C+K_5 \\ 2C+K_5 \\ 2C+K_3+K_5 \\ \ \ C+K_5 \end{array}\right| \begin{array}{l} C+K_5 \\ C+K_5 \\ C+K_5 \\ C+K_4+K_5 \end{array} \left|\left|\begin{array}{l} 4(C-1)+K_5 \\ 3(C-1)+K_5 \\ 2(C-1)+K_5 \\ \ \ (C-1)+K_5 \end{array}\right|\right. \ldots\ldots \quad (15)$$

§7. *Lap Joints.*

In lap joints the loads on the two plates are not in the same straight line. This causes bending of the plates, and the distribution of stress may be considerably modified by this action. The rivets are in single shear, and this will affect the value of K. In view of these factors and in the absence of experimental data, no attempt will be made in the present contribution to give a complete theory of such joints. If the bending of the plates is neglected, the work equation for a lap joint having a single line of rivets and connecting two similar plates will be

$$\begin{aligned} 2EW = {} & \frac{l}{a_p}\left[(F-X_1)^2+(F-X_1-X_2)^2+\ldots\ldots+(F-\Sigma X)^2\right] \\ & +\frac{l}{a_p}\left[X_1^2+(X_1+X_2)^2+\ldots\ldots+(\Sigma X)^2\right] \\ & +k\left[X_1^2+X_2^2+\ldots\ldots+(F-\Sigma X)^2\right] \end{aligned}$$

where a_p is the cross-sectional area of the plates.

Differentiating with respect to X_1, and equating the result to zero,

$$\begin{aligned} & -\frac{2l}{a_p}\left[(F-X_1)+(F-X_1-X_2)+\ldots\ldots+(F-\Sigma X)\right] \\ & +\frac{2l}{a_p}\left[X_1+(X_1+X_2)+\ldots\ldots+(\Sigma X)\right] \\ & +2k\left[X_1-(F-\Sigma X)\right]=0 \end{aligned}$$

Thus, if $K=\frac{k\cdot a_p}{l}$, the equations are

$$\left|\begin{array}{c|c|c|c|c||c|} (n-1)+2K & (n-2)+K & (n-3)+K & \ldots & 1+K & (n-1)+K \\ (n-2)+K & (n-2)+2K & (n-3)+K & \ldots & 1+K & (n-2)+K \\ (n-3)+K & (n-3)+K & (n-3)+2K & \ldots & 1+K & (n-3)+K \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots & \ldots & \ldots\ldots \\ 1+K & 1+K & 1+K & \ldots & 1+2K & 1+K \end{array}\right. \qquad (16)$$

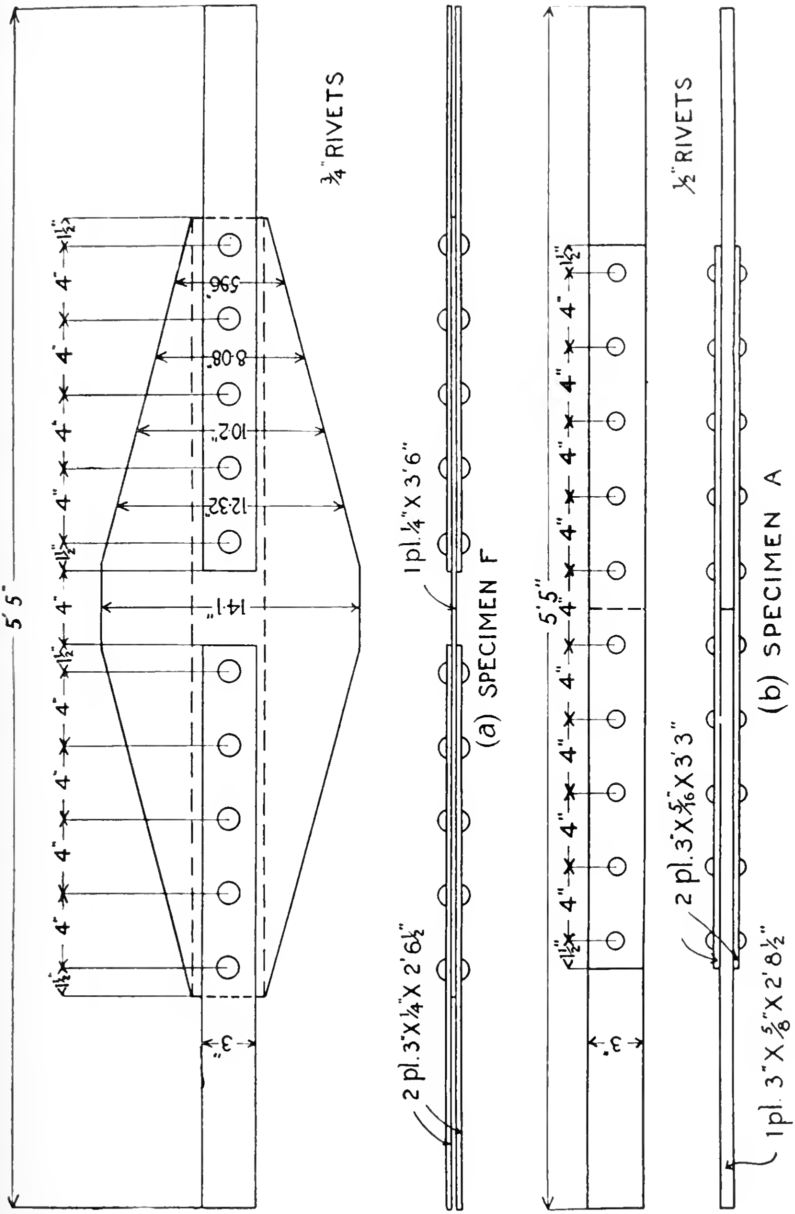
Thus the distribution of load is the same as for a butt joint having $C=2$, as considered in §2, if the value of K is the same. The above equations must be considered only as a first approximation.

PART II.—EXPERIMENTAL.

§1. *Specimens Used and Method of Experiment.*

The experiments described in the following pages were made with the object of determining the distribution of stress in the cover plates of a series of riveted butt joints having a single

FIG. 6.



Typical specimens.

line of rivets, and of thus deducing the load transferred from the main plate to the cover plates by each rivet. In order to establish the validity of the method, tests were also made on a specimen of the form shown in Fig. 6*a*, in which it was possible to measure the distribution of stress over a great part of the middle plate in addition to the distribution over the cover plates (see § 2). The butt joints were all of the form shown in Fig. 6*b*. The plates were of varying thicknesses and the rivets of various sizes, but the width of the plate was in every case three inches, the pitch of the rivets four inches, and the total number of rivets was ten; *i.e.*, five on each side of the junction. The annexed table shows the remaining dimensions and the designation of the specimens.

Specimen A was also tested with the first rivet removed, leaving four rivets on one side of the junction, and then with the fifth rivet removed, leaving three rivets.

Specimen F was also tested after the middle plate had been cut down to a uniform width of 4.09 inches, as shown by the dotted lines in Fig. 6*a*. This specimen will be designated by F^1.

All the specimens were made by the Dominion Bridge Company, Montreal. The holes were drilled and the riveting was done by machine. Care was taken to keep the specimens as free from local bending as possible, but otherwise the joints were ordinary shop products, and as such were subject to minor irregularities in the position of the holes, etc.

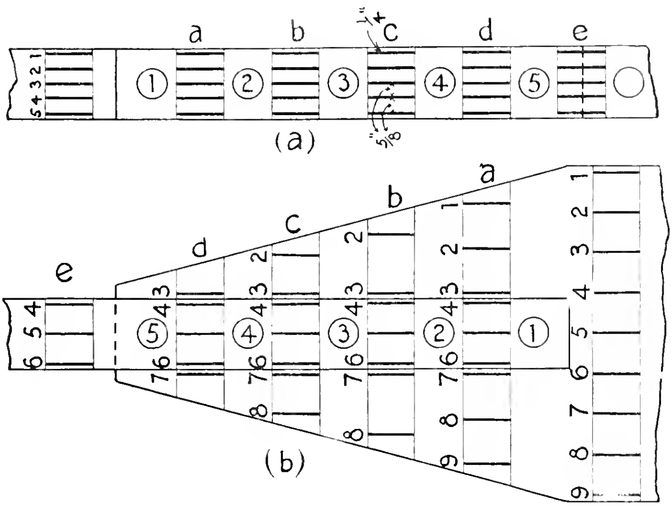
The strains were measured with the simplified form of the Marten's Mirror Extensometer developed in the McGill University Testing Laboratory. This instrument was described fully in a paper by the present writer which appeared in the JOURNAL OF THE FRANKLIN INSTITUTE, August, 1915.[11] The gauge length was 2 inches and the instrument read accurately to $\frac{1}{100,000}$ inch. All the instruments were carefully calibrated. The extensometers were set between each pair of rivets in positions such as are indicated in Fig. 7, their length being parallel to the axis of load. In specimens A and C, readings in five positions were taken between each pair of rivets; in B, D, E and F, in three positions only. In every case the instruments were read with the

[11] C. Batho, "The Effect of the End Connections on the Distribution of Stress in Certain Tension Members," J. F. I., August, 1915, p. 129.

knife-edge at each end in turn and the mean of these readings taken in order to eliminate errors due to bending. The strains measured in this way may be regarded as proportional to the stresses, since the strains perpendicular to the axis of load are so small as to be negligible. Readings taken on the middle plate below the joint and on the cover plates at the central section enabled the value of the modulus of elasticity for each plate to be determined.

The specimens were loaded in the 150,000-pound Emery testing machine at McGill University. This machine is of the

FIG. 7.



Positions of Extensometers.

vertical type and is very suitable for extensometer work because of the entire absence of vibration. The tests were carried out in a uniform manner. Four, or in some cases two, extensometers being placed in position and the mirrors set under an initial load of 100 pounds, the maximum load was applied and removed several times, the mirrors reset if necessary, and the load was then run up gradually, readings being taken at the required loads. The load was then reduced to its initial value. In nearly all cases the extensometer readings returned to zero. If not, the process was repeated until they returned satisfactorily. This latter precaution was, however, seldom necessary.

It will be seen that the success of the method depends upon the distribution of stress remaining the same after many loadings. This point was very carefully tested by repeating readings at intervals. No differences were found that were not within the range of experimental error; *i.e.*, the readings checked to $\frac{1}{100,000}$ inch. An attempt was made in specimen A to obtain readings on the first loading of the piece. This was found rather difficult as the ends of the specimen always slip a little in the grips when the load is applied for the first time, disturbing the extensometers, so that the loading has to be carried out in stages, returning to the initial load and resetting the extensometers every time such a motion occurs. The results appeared to show some minor differences between the distribution of stress on the first and on subsequent loadings, but these may have been due to experimental errors. A closer examination of this matter would be interesting, but outside the scope of the present investigation, which deals with the distribution of stress in joints when a stable condition has been reached, and, as stated above, this distribution remains exactly the same, no matter how many times the piece has been loaded.

The specimens were loaded in tension. Experiments in compression would be more difficult because of the tendency for bending to occur, but would be necessary in order to determine the value of K for joints in compression.

§2. *Test of the Validity of the Method.*

The object of the experiments, as stated above, was to obtain the proportion of the load transmitted from the middle plate to the cover plates by each rivet. Since extensometer measurements could be taken only on the outer surfaces of the cover plates, it will be seen that the validity of the method depends upon whether or no the strains in the cover plates deduced from these measurements were a true estimate of the mean strains in the plates. If, for example, the plates were held together mainly by friction between the plates, the stresses at the inner surfaces of the plates would probably be much greater than at the outer. In order to obtain information on this point, experiments were made on specimen F, in which the middle plate was much wider than the outer plates, so that measurements could be taken both

on the cover plates and on the middle plate. The extensometer positions are shown in Fig. 7, and Table IV gives the sum of the four extensometer readings on the two sides of the specimen at each position, one-hundred-thousandth of an inch being taken

TABLE IV.

Section	Sum of the extensometer readings on the two faces of the specimen								
	1	2	3	4	5	6	7	8	9
Central section of middle plate	76	100	113	167	179	162	130	101	70
a	103	110	112	76	67	77	126	118	107
b		122	107	110	90	109	117	111	
c		119	121	140	114	142	124	126	
d			123	162	150	166	128		
e				279	281	281			

as unit, for a tensile load of 16,000 pounds. The extensions were measured over a length of 2 inches. Thus, since the readings are correct to $\frac{1}{100,000}$ inch, an error of about 150 pounds, *i.e.*, about 1 per cent. of the load, is possible in the estimate of the stress. The error of the sum is probably much less than this.

TABLE V.

E = 28.4 × 10⁶ pounds per square inch for middle plate,
= 30.4 × 10⁶ pounds per square inch for outer plates.

Section	Mean strain in middle plate × 4 $\left(\frac{1}{100,000}\right)''$	Mean strain in outer plate × 4 $\left(\frac{1}{100,000}\right)''$	Load carried by middle plate Lbs.	Load carried by outer plates Lbs.	Total load from extensometer reading Lbs.	Error
						Per cent.
Central	127.7	.....	16000	.....	16000	.....
a	112.7	71.7	12320	4100	16420	+2.62
b	114.2	99.7	10340	5690	16030	+0.19
c	122.5	127.5	8800	7260	16060	+0.38
d	125.5	157.0	6650	8940	15590	−2.56
e	.....	280.5	.....	16000	16000	.....

The values of *E* for the plates were determined from the readings at the central section for the middle plate, and at section *e*, below the rivets, for the outer plates. The results are given at the head of Table V.

Columns 1 and 2 in Table V give the mean strains at each

section determined from the figures in Table IV. To obtain the mean strains in the outer plates, twice the middle reading was added to the two outer readings and the result divided by four. Thus at section *a* the mean strain

$$71.7 = \frac{76 + 2 \times 67 + 77}{4}.$$

The reason for this will be explained in §3. The mean strains in the inner plate were obtained by taking the average of the figures given in Table IV. The loads carried by the outer and inner plates respectively were calculated by using the values of E obtained as explained above and are given in columns 3 and 4 of Table V.

At each section the sum of these, if the estimated strains are the mean strains in the plates, should be 16,000 pounds, the total load. The actual sums are given in column 5, and it will be noticed how close they are to this value. The percentage errors are given in column 6. They are quite negligible at sections *b* and *c* and only amount to about 2.6 per cent. at sections *a* and *d*. Thus the validity of the method may be regarded as fully established. The agreement of the results will be seen to be remarkably close when it is considered that the experimental error may amount to about 1 per cent. and that readings could not be taken over the parts of the middle plates covered by the outer plates.

It may occur to the reader that there is also an error due to the varying width of the middle plate not being taken into account in reducing the strains to stresses. This error, however, was estimated and found to be too small to be considered.

To sum up, the above experiment shows that extensometer measurements on the outside of the outer plates of a riveted joint are sufficient for the determination of the proportion of the load carried by each rivet, since they give accurate values for the mean strains in the plates. It also appears to prove that friction between the plates cannot play any part in transferring the load, except possibly in the parts of the plates close to the rivets.

§3. *Experimental Results for Specimens A, B and C in Which the Thickness of Each of the Cover Plates was One-half the Thickness of the Middle Plate.*

The results of the tests on specimens A, B, and C are given in Table VI, together with their reduction to find the load taken by each rivet. It has not been considered necessary to tabulate each individual extensometer reading. The figures in Table VI are the sums of the four readings at the corresponding positions on the two cover plates, the sum being given, for convenience, instead of the mean. Readings were also taken on the middle plates below the joint for the purpose of determining E for these plates, but are not tabulated.

The earlier experiments were made on specimens B, D, E and F, and in these readings were taken in three positions only at each cross-section, corresponding to 1, 3 and 5, Fig. 7. The results (see Table VI) showed clearly that the distribution of strain across the width of the plates was not uniform, the readings at the central position being always less than at the outer positions. It was therefore thought to be advisable to take readings at the intermediate positions, 2 and 4, Fig. 7, in order to study more closely the actual distribution of strain. This was done in specimens A and C.

The results for these specimens given in Table VI show that the distribution of strain is of substantially the same character at all loads and for each specimen. The strain is always least at the centre, rising to a maximum at each outer boundary. The readings for specimen A at the cross-section, between the fourth and fifth rivets, where the variations are most marked, are plotted in Fig. 8. It will be noticed that the shape of the curves is the same at all loads. The ratio of the mean of the readings at 1 and 5 to the reading at 3 has the values

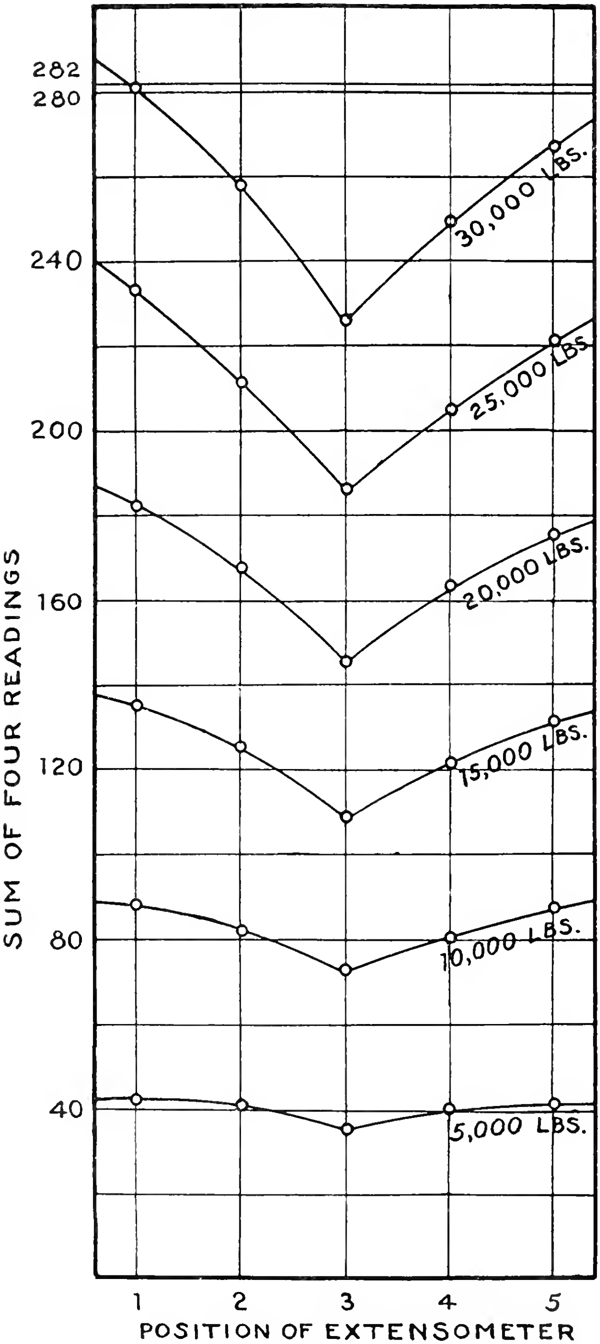
1.15, 1.20, 1.22, 1.23, 1.22, 1.21

at the loads

5000, 10000, 15000, 20000, 25000, 30000 pounds

respectively. It thus remains practically constant for all loads from 10,000 pounds to 30,000 pounds. It is somewhat less at the 5,000 pound load, but the readings for this load are too small to be relied upon. Curves drawn for the other sections give similar results. Now the maximum load on this specimen, 30,000 pounds, corresponds to an average stress of about 15,280 pounds per square inch of rivet, well above the working stress. Thus, at any rate when the joint has come to a stable condition

FIG. 8.



Distribution of strain at different loads between the fourth and fifth rivets of specimen A.

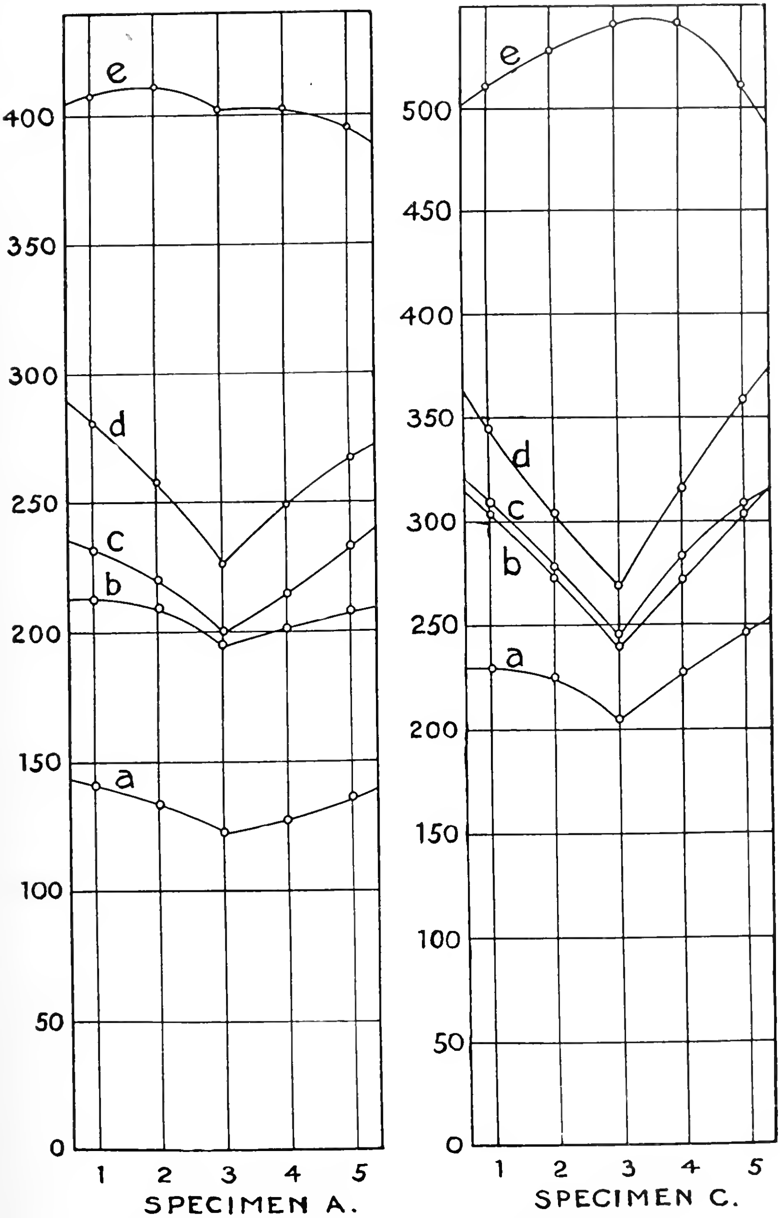
1	2																									3					4					5	6
Load	Sum of the four extensometer readings in corresponding positions on the two faces of the specimen																									Mean of the readings at each section (obtained as described on page 577)					Percentage of the total load taken by each rivet					Mean of 1 and 5.	K
	a					b					c					d					e																
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	a	b	c	d	e	1	2	3	4	5		
A . E for middle plates = 30.4 × 10⁶ lbs. per sq. in., E for cover plates = 31.7 × 10⁶ lbs. per sq. in.																																					
5000	29	28	28	28	31	36	36	33	35	36	37	36	34	36	38	42	41	36	40	41	66	68	67	63	61	28	35	36	40	65	43.2	10.8	1.5	6.2	38.3	40.7	.....
10000	60	60	55	57	61	73	70	65	69	73	75	72	66	70	75	88	82	73	80	87	134	137	134	135	126	58	69	70	80	133	43.6	8.3	0.8	7.5	39.9	41.7	0.485
15000	85	83	77	80	85	108	107	102	114	111	113	109	99	108	115	135	125	109	121	131	200	202	200	196	192	81	108	108	122	198	40.9	13.6	0.0	7.1	38.4	39.6	0.673
20000	105	102	95	100	103	147	142	133	142	145	151	148	131	145	154	182	168	145	163	175	272	274	266	263	258	100	141	147	164	267	37.5	15.4	2.2	6.4	38.6	38.1	0.837
25000	124	120	112	113	116	181	175	162	170	176	192	185	163	180	194	233	211	186	205	221	343	344	336	337	329	116	172	181	207	338	34.4	16.5	2.7	7.7	38.8	36.6	1.027
30000	141	134	123	127	136	214	209	195	201	208	232	222	200	214	233	281	258	226	249	267	408	411	402	402	395	131	204	217	252	404	32.4	18.0	3.2	8.7	37.6	35.0	1.300
A with 5th rivet removed.																																					
5000	36	32	32	32	35	40	37	36	35	38	45	39	37	39	43	...	...	...	...	...	...	...	...	...	...	33	36	40	...	...	50.8	4.6	6.1	38.5	...	44.6	0.273
10000	62	60	59	59	62	78	71	67	69	73	97	80	73	78	94	...	...	...	...	...	...	...	...	...	...	60	70	81	...	...	45.0	7.5	8.3	39.1	...	42.0	0.475
15000	89	83	83	86	94	115	105	104	105	111	141	122	111	120	138	...	...	...	...	...	...	...	...	...	...	86	106	122	...	...	43.5	10.1	8.1	38.4	...	40.9	0.573
20000	109	104	101	104	109	151	142	137	140	149	191	166	155	163	184	...	...	...	...	...	...	...	...	...	...	104	142	167	...	...	39.0	14.2	9.3	37.5	...	38.2	0.900
25000	126	119	120	125	129	199	177	172	174	184	241	209	195	205	235	...	...	...	...	...	...	...	...	...	...	123	177	210	...	...	36.4	16.0	9.8	37.0	...	37.1	1.066
30000	143	135	132	143	153	228	212	208	211	220	294	257	239	252	281	...	...	...	...	...	...	...	...	...	...	140	213	257	...	...	34.6	18.0	10.9	36.4	...	35.5	1.380
A with 1st and 5th rivets removed.																																					
5000	...	...	...	...	...	37	34	34	35	35	45	39	36	39	42	...	...	...	...	...	...	...	...	...	...	...	35	39	...	...	...	53.9	6.1	40.0	...	47.0	0.150
10000	...	...	...	...	...	64	62	62	66	65	96	83	69	79	99	...	...	...	...	...	...	...	...	...	...	...	63	81	...	...	...	47.4	13.5	39.1	...	43.3	0.450
15000	...	...	...	...	...	95	92	91	92	92	139	127	105	120	135	...	...	...	...	...	...	...	...	...	...	...	92	122	...	...	...	46.5	15.1	38.4	...	42.5	0.545
20000	...	...	...	...	...	116	112	112	119	119	184	168	143	166	177	...	...	...	...	...	...	...	...	...	...	...	115	165	...	...	...	43.1	18.7	38.2	...	40.7	0.825
25000	...	...	...	...	...	143	141	137	143	140	238	211	183	208	221	...	...	...	...	...	...	...	...	...	...	...	141	208	...	...	...	41.8	19.8	38.5	...	40.1	0.975
30000	...	...	...	...	...	164	160	165	169	164	286	259	229	251	269	...	...	...	...	...	...	...	...	...	...	...	164	254	...	...	...	40.6	22.3	37.2	...	38.9	1.320
C . E for middle plate = 29.4 × 10⁶ lbs. per sq. in., E for cover-plates = 30.4 × 10⁶ lbs. per sq. in.																																					
16000	135	129	119	131	148	161	146	127	147	161	161	149	132	152	161	175	155	135	156	182	264	282	299	292	265	130	146	149	156	280	46.5	5.7	1.1	2.5	44.3	45.4	0.225
20000	167	160	148	163	180	204	180	160	182	203	202	186	164	190	204	220	197	168	199	230	335	347	371	358	340	161	181	187	198	350	40.0	5.7	1.7	3.1	43.5	44.7	0.260
25000	199	192	180	201	215	253	227	200	220	254	255	232	205	235	259	278	246	215	250	288	420	439	457	450	423	195	227	232	248	438	44.5	7.3	1.1	3.6	43.5	44.0	0.314
30000	229	224	204	227	246	304	273	239	272	304	309	278	245	284	308	345	304	269	316	359	511	529	542	542	511	223	272	280	310	527	42.4	9.3	1.5	5.7	41.2	41.8	0.477
35000	258	249	235	261	280	354	319	277	319	356	360	326	285	335	365	406	361	320	368	425	595	617	629	635	605	254	318	328	365	616	41.2	10.4	1.6	6.0	40.7	41.0	0.545
B . E for middle plate = 30.1 × 10⁶ lbs. per sq. in., E for cover plates = 31.3 × 10⁶ lbs. per sq. in.																																					
16000	142	...	128	...	146	151	...	136	...	151	161	...	139	...	163	188	...	147	...	193	271	...	277	...	280	136	143	150	160	276	49.3	2.5	2.5	6.0	38.8	44.1	0.306
20000	173	...	153	...	170	199	...	169	...	200	199	...	167	...	197	234	...	184	...	246	343	...	347	...	345	164	184	182	212	345	47.6	5.8	−0.6	8.7	38.6	43.1	0.360
22000	189	...	160	...	194	217	...	182	...	222	219	...	182	...	210	265	...	204	...	270	378	...	382	...	379	180	201	200	237	380	47.5	5.5	−0.3	9.7	37.6	42.5	0.423
27000	201	...	205	...	247	244	...	220	...	279	257	...	223	...	280	322	...	250	...	337	462	...	468	...	464	214	241	246	290	465	46.0	5.8	1.1	9.4	37.7	41.8	0.477
30000	221	...	224	...	270	260	...	243	...	313	287	...	253	...	310	365	...	277	...	380	514	...	522	...	519	236	267	276	325	518	45.6	5.9	1.7	9.5	37.3	41.5	0.500
33000	241	...	244	...	293	299	...	269	...	344	320	...	273	...	344	406	...	307	...	425	563	...	573	...	572	256	295	302	301	569	45.0	6.9	1.2	10.3	36.6	40.8	0.564

after a few loadings, the manner of distribution of stress in the plates remains the same at all loads. This does not mean that the rivets carry the same proportions of the total load, but that there is no marked change in the way in which the load is transferred to the plates by the rivets.

It would require too much space to give all the curves for specimens A and C, and it is, fortunately, unnecessary, since they are, as shown above, similar for the same sections at different loads. Fig. 9 shows the readings at all the sections of the cover plates in specimens A and C for a load of 30,000 pounds. It will be remembered that the rivets in specimen A are ½ inch diameter and in specimen C are ⅞ inch diameter, the thickness of the cover plates being ¼ inch in specimen A and 5/16 inch in specimen C. In order to make direct comparison possible the ordinates of the curves for specimen A have been drawn to 5/4 the scale of the ordinates for specimen C, thus allowing for the difference in thickness of the plates. The curve at the central section, *c*, is higher in specimen C than in A, indicating that the value of E is lower in specimen C than in A. The actual values are 31.7×10^6 pounds per square inch for A and 30.4×10^6 pounds per square inch for C. Thus the ordinates do not represent the *stresses* in the two specimens to quite the same scale. The curves for sections *a*, *b*, *c* and *d* are very similar in form in the two specimens, although the load, 30,000 pounds, corresponds to an average load of about 15,280 pounds per square inch of nominal rivet section in A and of only 15,280 pounds per square inch in C, showing that the manner of distribution of stress at a cross-section is substantially the same not only at different loads, as shown above, but also in different specimens. All the experimental results show this in an equally striking manner. The curves are not quite symmetrical about the centre line. This is probably due to slight irregularities in the construction of the specimens. Most of the curves seem to show a discontinuity at the centre, position 3. Readings taken close to the centre might show that the curve is really continuous instead of coming to a sharp point.

The curves referred to above represent the sum of the readings in corresponding positions on the two cover plates and thus give (as shown in §2) the mean strain in the cover plates multiplied

FIG. 9.



Distribution of strains in specimens A and C at a load of 30,000 lbs.

by four. Fig. 10 shows, to the same scale as Fig. 9, the readings on the two cover plates for specimen A at 30,000 pounds load. Owing to bending in the plates, and slight irregularities in the placing and action of the rivets, the strain in one cover plate is at each section higher than in the other, the ratio varying somewhat at different sections. This has a slight effect upon the partition of load between the rivets, as was proved in Part I, § 3. The difference in the value of E for the cover plates and the middle plates has a similar effect.

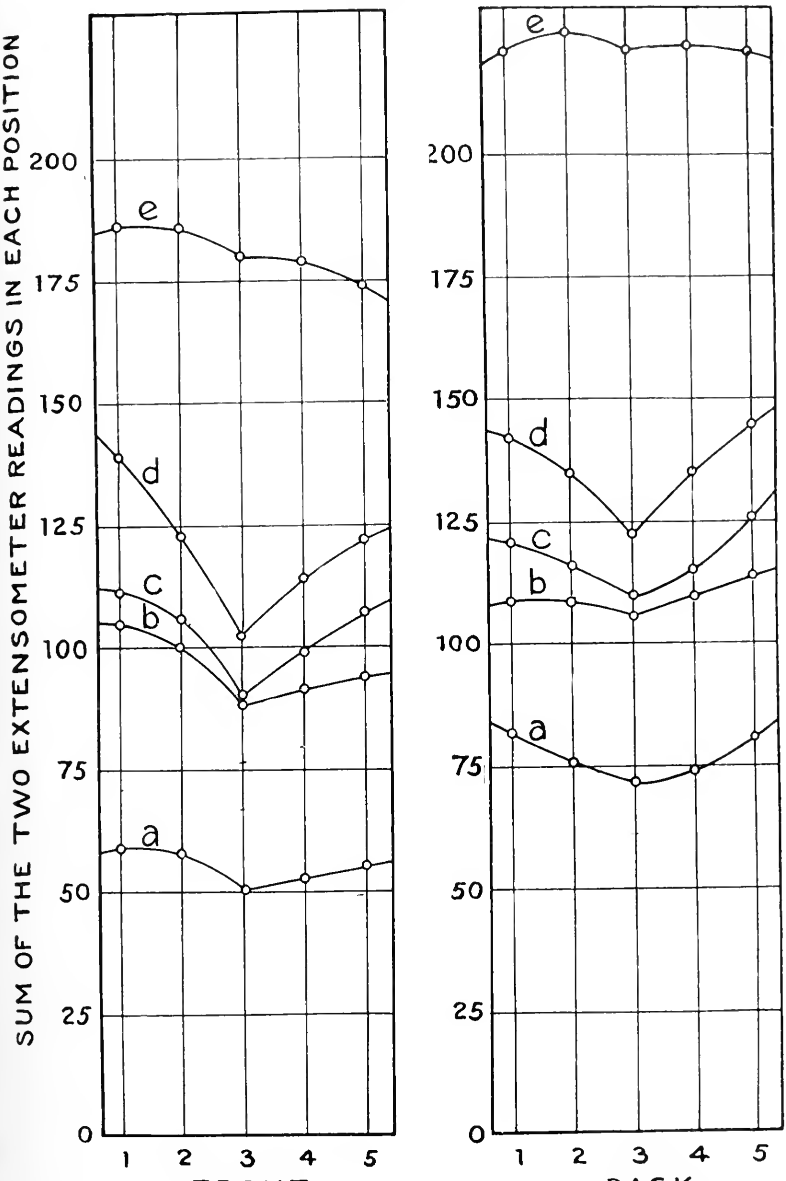
The curves given in Fig. 9 show that the ratio of maximum to minimum stress, or strain, across the section is least between the first and second rivets and increases to a maximum between the fourth and fifth rivets. This fact and the general form of the curves lend strong support to the view that the rivets are acting in shear, because, if the plates were, in the neighborhood of the rivets, held together by friction, it would seem that the pull transferred by each rivet would give a maximum stress at the centre line and a minimum at the outer edges. Also, it is very unlikely that in such a case the strains on the outer faces of the cover plates would give true values for the mean strains in the plates.

The area included between the curve for section e, the ordinates at its ends, and the horizontal axis is a measure, to some scale, of the total load on the specimen. The areas under curves a, b, c and d represent to the same scale the loads at the corresponding sections of the cover plates. Thus the area under a represents the load transferred to the cover plates by the first rivet, the area between a and b the load transferred by the second rivet, etc. It is at once evident that the first and last rivets transfer the major portion of the load and that the middle rivet transfers practically nothing. This is in accordance with the theory given in Part I. In order to obtain the exact loads taken by each rivet, all that is necessary is to obtain the mean heights of the curves. This has been done, and the results are given in Table VI, column 3. It was found that the mean corresponding to the curves could best be determined by using Simpson's rule on each side of the centre. Thus, for example, the mean for specimen A at section d for a load of 30,000 pounds is given by

$$\frac{281+4\times258+2\times226+4\times249+267}{12}=252,$$

the result being taken to the nearest integer.

FIG. 10.



Extensometer measurements on the two cover plates of A, at a load of 30,000 lbs.

For specimens B, D, E and F, since three readings only were taken, the mean was considered as the sum of the readings at 1 and 5, together with twice the reading at 3, the whole being divided by 4. Applied to the section of specimen A considered above, this would give 250 instead of 252, a difference of about 0.8 per cent. Thus the error from using three readings only is unimportant.

The mean strains are proportional to the loads in the cover plates at the different sections, and the proportion of the load taken by each rivet may readily be found from these. For example, for specimen A at 30,000 pounds load, the mean at section e is 404, and at section a is 131. Thus the first rivet takes

$$\frac{131}{404} \times 100 = 32.4 \text{ per cent.,}$$

the second rivet takes

$$\frac{204-131}{404} \times 100 = 18 \text{ per cent.,}$$

of the total load, etc.

Column 4, Table VI, gives the percentage of the total load taken by each rivet for the specimens A, B and C at different loads, and also for specimen A with the fifth rivet removed and with the first and fifth rivets removed. It will be at once apparent that the results are in general agreement with the theory given in Part I, the end rivets taking by far the greater portion of the load, the second and fourth rivets much less, and the centre rivet practically none.

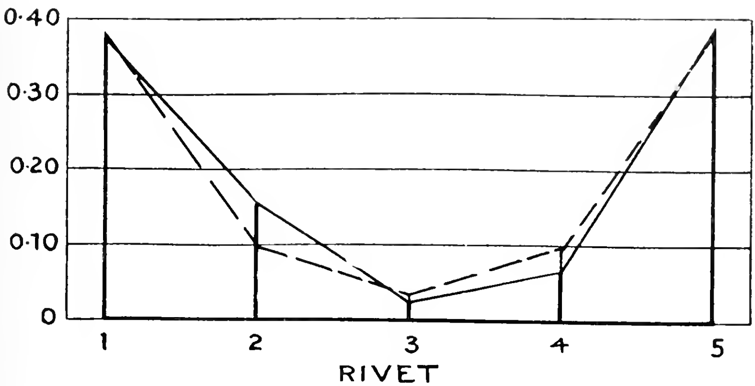
Column 5 gives the mean of the percentages of the load taken by the two end rivets, and it will be noticed that in every case this decreases as the load increases, which means that the value of K increases with the load. This point will be discussed in the next section. The general distribution is, however, similar at different loads, and Figs. 11 to 15 show typical results graphically.

Figs. 11, 12 and 13 show the partition of the load between the rivets for specimen A at a load of 20,000 pounds with five, four, and three rivets respectively, and Figs. 14 and 15 show the same for specimens B and C respectively at a load of 30,000 pounds.

The heavy ordinates represent the proportions of the total load taken by each rivet. The tops are joined by lines in order to display the results more clearly. These lines do not, of course, mean that interpolations may be made for a different number of rivets.

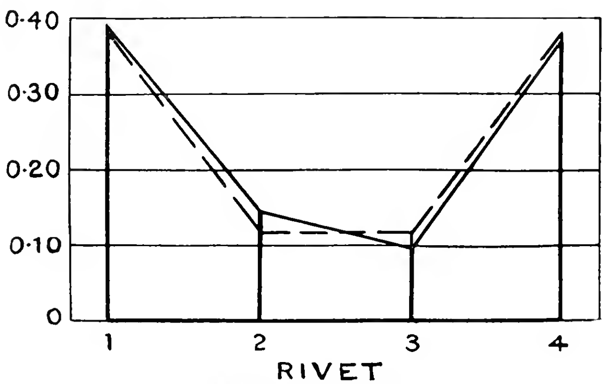
The distribution is not quite symmetrical in any of the

FIG. 11.



Specimen A. Load 20,000 lbs.

FIG. 12.

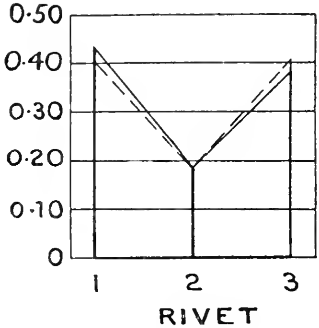


Specimen A (4 rivets). Load 20,000 lbs.

specimens, the last rivet, except for the three highest loads on specimen A and the two highest on the same specimen with the fifth rivet removed, taking a little less of the load than the first. This is, probably, mainly due to the causes discussed in Part I,

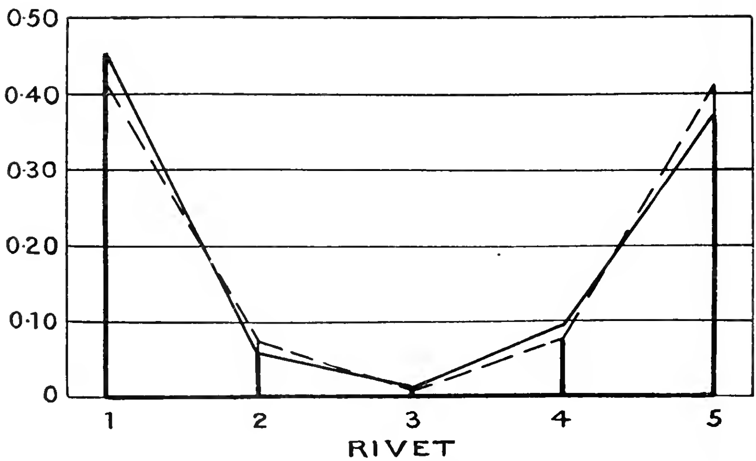
§ 3, *i.e.*, the difference in the values of E for the main plate and the cover plates and the unequal loads taken by the two cover plates; but want of straightness and minor irregularities in the specimens may also play some part. The difference is most

FIG. 13.



Specimen A (3 rivets). Load of 20,000 lbs.

FIG. 14.

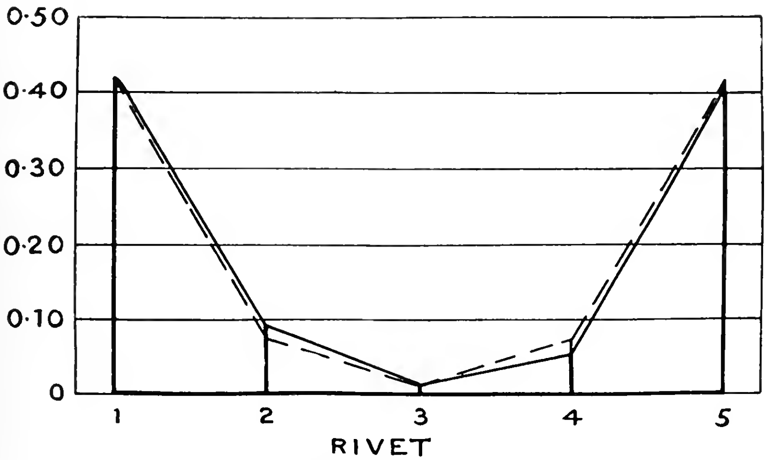


Specimen B. Load 30,000 lbs.

marked in specimen B, and practically vanishes in specimen C. In order to determine the value of K best fitting the experimental results, the mean of the loads taken by the first and last rivets was used, and from this K was determined, as described in Part I, by the use of Fig. 2, Part I. The values thus found are given in the last column of Table VI.

The dotted lines in Figs. 11 to 15 show the theoretical percentages of the load taken by each rivet, obtained by using these values of K. The agreement between the theoretical and experimental results is very striking, especially if it be remembered that the specimens were by no means ideal, but ordinary shop products. The experimental results for the rivets 2, 3 and 4 are somewhat irregular. This may be partly owing to experimental errors, since the results depend upon the comparatively small differences between the means of the readings at consecutive cross-sections of the plates, but it may also arise from taking the value of K as constant for all rivets. In any case, these rivets take such small loads that the differences between the theoretical and experimental results may be regarded as unimportant.

FIG. 15.

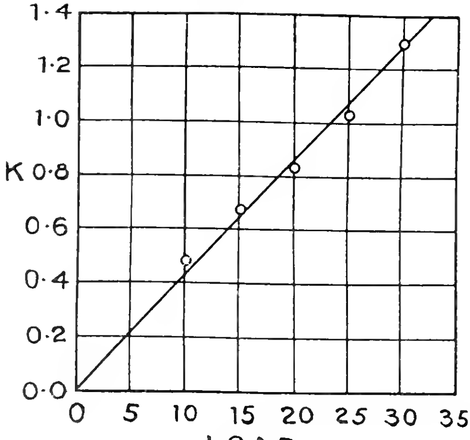


Specimen C. Load 30,000 lbs.

§ 4. *The Value of K.*

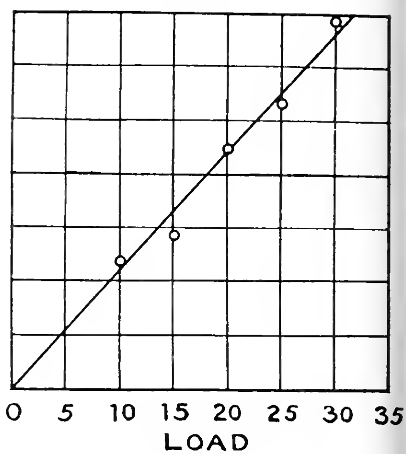
The values of K given in Table VI, column 6, are plotted in Figs. 16 to 20. Since a small variation in the percentage of the load carried by the end rivets causes a fairly large variation of K, the results cannot be considered as accurate to the third place of decimals, and the range of error is roughly indicated by the circles marking the experimental points in the figures. The variation of K with the load is somewhat irregular, but the points lie fairly well on straight lines except for specimen C. Probably

FIG. 16.



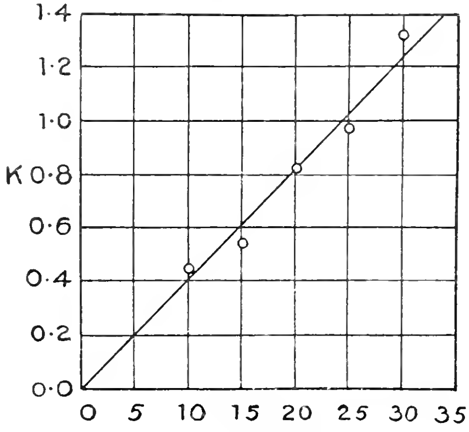
Specimen A.

FIG. 17.



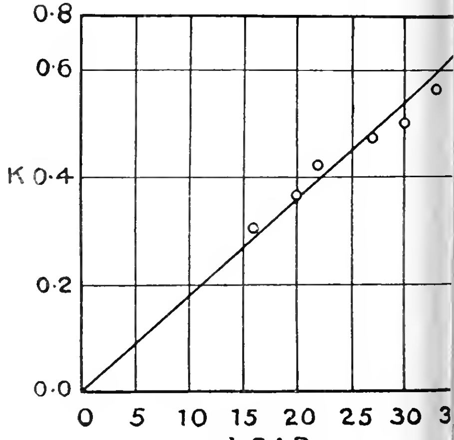
Specimen A, (4 rivets)

FIG. 18.



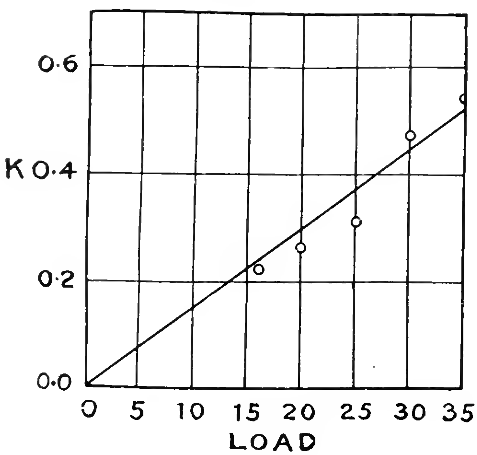
Specimen A, (3 rivets)

FIG. 19.



Specimen B.

FIG. 20.



Specimen C.

FIGS. 16–20. Variation of K with load. Unit of load 1000 lbs.

with more carefully made specimens the irregularities would disappear. In any case the law of variation may be regarded, for practical purposes, as linear. In order to obtain the mean straight lines, the method of least squares was used; *i.e.*, if F_n represent the abscissa (load), K_n the ordinate (K) of any point, the law of variation was taken as

$$K = \frac{\Sigma F_n K_n}{\Sigma F_n^2} \cdot F \cdot$$

The results are given, correct to two figures, in the annexed Table.

TABLE VII.

Specimen	Diameter of rivets	Law of variation of K with load
C	7/8″	$K = 0.15 \times 10^{-4}$ F
B	3/4″	$K = 0.18 \times 10^{-4}$ F
A	1/2″	$K = 0.43 \times 10^{-4}$ F
A (4 rivets)	1/2″	$K = 0.44 \times 10^{-4}$ F
A (3 rivets)	1/2″	$K = 0.41 \times 10^{-4}$ F

The results differ but little for the three specimens with ½-inch rivets, although the number of rivets was different. On the other hand, there is a considerable difference between the values for the specimens A, B and C, the ratio of K's for any given load being

$$K_A : K_B : K_C = 2.87 : 1.2 : 1.$$

Now the nominal diameters of the rivets in A, B and C are ½ inch, ¾ inch, and ⅞ inch respectively, and the inverse ratio of their areas is as

$$3.07 : 1.34 : 1$$

Thus the values of K are roughly in inverse proportion to the nominal areas. A number of rivets were removed from these specimens, and it was found that the rivets fitted tightly in the holes, while the holes were somewhat irregular but always greater in diameter than the nominal diameter of the rivet, the mean diameters being 0.55 inch for specimen A, 0.83 inch for specimen

B, and 0.925 inch for specimen C. Thus the inverse ratio of the actual areas is as

$$2.83 : 1.24 : 1,$$

which is very close to the ratio of K's. It therefore appears that the values of K vary as $\frac{F}{A}$, where F is the total load on the specimen and A the area of cross-section of the rivets. This being so, an empirical formula for K is

$$K = \frac{a F}{10^{-4} A},$$

where a is a constant. The values of a given by the experimental results are 0.102, 0.098, and 0.101 for the specimens with ½-inch, ¾-inch, and ⅞-inch rivets respectively. Thus the mean value is 0.100 and

$$K = \frac{F}{100{,}000 A} \cdot \qquad (17)$$

where A is the actual area of cross-section of the rivets. This result indicates that in joints similar to the specimens A, B and C the value of K is the same for the same average load per square inch of total cross-section of the rivets. For example, at a load of 10,000 pounds per square inch of total cross-section of the rivets $K = 1.0$. On the other hand, the results for specimen A with the fifth rivet and with the first and fifth rivets removed show very little change in the value of K with the number of rivets. The results of these tests, however, cannot be taken as conclusive, because the rivets had been previously under stress in the complete specimen.

It will be shown in the next section that the value of K given by equation (17) gives results in accordance with the experimental results for the remaining specimens. This says much for the truth of the theory given in Part I, and shows that equation (17) is correct for specimens such as have been tested. It will be necessary, however, to make many more experiments on specimens in both tension and compression having different sizes and arrangements of rivets and different ratios of width of cover plate to rivet pitch before general rules can be given for the determination of K in any type of joint.

Equation (17) is entirely empirical. It will be interesting to examine the results theoretically. K, as explained in Part I, § 2, is a coefficient given by

$$K = \frac{2a_c}{l} \cdot k \cdot$$

where k is that quantity which, when multiplied by the square of the load transferred by a rivet and divided by $2E$, gives the work stored in the rivet or its equivalent. It is not easy to determine in exactly what manner work is stored in the rivets. Possibly the rivets act by giving a frictional hold between the plates. This does not seem probable, since K follows the same laws below and above loads at which slip has been shown to occur by other investigators, and because of other reasons already given. If, however, the rivets do hold by friction, K must be some function depending upon the work stored in the portions of the plate held together without slip by the rivets. If, on the other hand, the rivets are in shear, $\frac{kP^2}{2E}$ is the work stored in them when transmitting a load P. Now the rivets are so short and so rigidly held that the work stored in bending must be very small and the major portion of $\frac{kP^2}{2E}$ must be the work stored in shear. This will depend upon the exact manner in which the load comes upon the rivets. As the load increases the contact between plates and rivets will become more intimate and thus the value of K will increase. This is precisely what was found in the experiments. It is, of course, impossible to say theoretically how the load will be distributed at any particular stage. Assuming, however, that a load has been reached which gives a uniform load distribution over the length of the rivets, the shearing force on the rivet will increase uniformly from zero at the head to a maximum of $\frac{P}{2}$ at the junction of the cover and middle plates and will then decrease uniformly to zero at the centre of the middle plate. The intensity of shear, q, at any point of a cross-section over which the shearing force is S will be given by

$$q = \frac{4S}{3\pi R^2}\left(1 - \frac{y^2}{R^2}\right)$$

where R is the radius of the rivet and y the distance of the point

from an axis through the centre in the plane of the cross-section and perpendicular to the load.[12] The work stored by shear will be given by

$$W_s = \Sigma \frac{a^2}{2G} \cdot dV,$$

where G is the modulus of rigidity of the material and dV an element of the volume. This, omitting the analysis, gives

$$W_s = \frac{5}{54G} \cdot \frac{t}{A} \cdot P^2,$$

where t is the thickness of the middle plate, or twice the thickness of the cover plates.

Thus

$$K = \frac{5}{27} \frac{E}{G} \cdot \frac{t}{A}$$

and

$$K = \frac{2a_c}{l} \cdot \frac{5}{27} \cdot \frac{E}{G} \cdot \frac{t}{A}.$$

If b represents the breadth of the cover plate $a_c = \frac{bt}{2}$, and

$$K = \frac{5}{27} \cdot \frac{E}{G} \cdot \frac{b}{l} \cdot \frac{t^2}{A}. \qquad (18)$$

For specimen A, having a middle plate 3 inches wide and ⅝-inch thick and ½-inch rivets of 4 inches pitch, this would give, taking the nominal area of the rivets and $\frac{E}{G} = 2.5$,

$$K = 0.692.$$

This is of the same order as the experimental values; in fact, it is the actual value of K for a load of 16,000 pounds or an average load of 8150 pounds per square inch of rivet. If the work stored in bending were considered, the value would be raised somewhat. The value of K given by equation (18) varies inversely as A, and this would be true no matter how the load was distributed over the length of the rivet. This is in accordance with the experimental results. On the other hand, it varies as t^2 while the experimental results do not show such a variation. This would appear to indicate that at a given load per square inch of rivet

[12] See Morley, "Strength of Materials," p. 132. This assumes that the shear intensity is constant over an elementary slice of the cross-section perpendicular to the load.

the load is distributed in the same way and over the same length of the rivet, no matter what the total length of the rivet may be. This seems probable, at any rate for fairly short rivets. In this case K would vary with the ratio $\frac{b}{l}$. Further theorizing on this point, however, would be futile on the experimental evidence at present available.

To sum up, if the rivets act by clamping the plates together by their initial tension, it is evident from the experimental results of §2 that this action is local, and in this case K will depend on the way in which work is stored in the parts of the plates thus held. If, on the other hand, the rivets are in shear, K will depend principally upon the work stored in shear in the rivets and will vary at different loads, because the manner of distribution of the load on a rivet depends upon the intensity of the load. Theoretical considerations and experimental results both appear to show that the second hypothesis is the correct one, but further experiments are needed. It is, of course, quite possible that the value of K is not the same for all the rivets in a joint and that the values given above are only equivalent ones for the whole joint.

TABLE VIII.

Specimen	Section	Sum of extensometer readings on the two faces			Mean	Specimen	Section	Sum of extensometer readings on the two faces			Mean
		1	2	3				1	2	3	
D	a	145	119	143	132	F	a	76	67	77	72
	b	164	138	163	151		b	110	90	109	100
	c	173	144	166	157		c	140	114	142	127
	d	176	144	170	158		d	162	150	166	157
	e	195	170	197	187		e	279	281	281	280
E	a	187	170	192	180	F′	a	144	134	150	140
	b	216	183	212	198		b	175	156	179	166
	c	221	184	223	203		c	197	157	196	177
	d	228	191	226	209		d	215	178	227	199
	e	280	284	281	282		e	...	...	...	280

§5. *The Specimens D, E, F and F′.*

The experimental results for the specimens D, E, F and F′ under a load of 16,000 pounds are shown in Tables VIII and IX. The specimen F′ was, as mentioned above, obtained by cutting

down the middle plate of specimen F to a uniform thickness of 4.096 inches. This, of course, changed the partition of the load among the rivets, as may be seen by comparing Figs. 23 and 24.

The specimens D, E, and F′ will be considered first. The cover plates in specimens D and E were 3/8 inch and 1/4 inch thick respectively, the middle plate being 1/4 inch thick, and all plates 3 inches wide. All the plates of F′ were 1/4 inch thick, but the outer plates were 3 inches wide and the inner plate 4.096 inches. Thus the values of C in the specimens D, E and F′ were 4, 3 and 2.468 respectively. Now it will be remembered that the theory given in Part I indicated that, if C were greater than 2, the first rivet would take a greater percentage of the load than the last,

TABLE IX.

Specimen	C	K		Percentage of total load taken by each rivet				
				1	2	3	4	5
D	....	....	e	70.7	10.1	3.2	0.5	15.5
	4.04	0.29	t	70.5	4.4	0.4	1.5	23.2
E	....	....	e	63.8	6.4	1.8	2.1	25.9
	3.02	0.29	t	61.5	5.0	0.2	2.9	30.4
F′	....	....	e	50.0	9.3	3.9	7.9	28.9
	2.468	0.29	t	53.8	5.2	0.6	3.8	36.6
F	....	....	e	25.7	10.0	9.6	10.7	44.0
	2.468	0.29	t	28.7	8.0	6.6	11.6	45.0

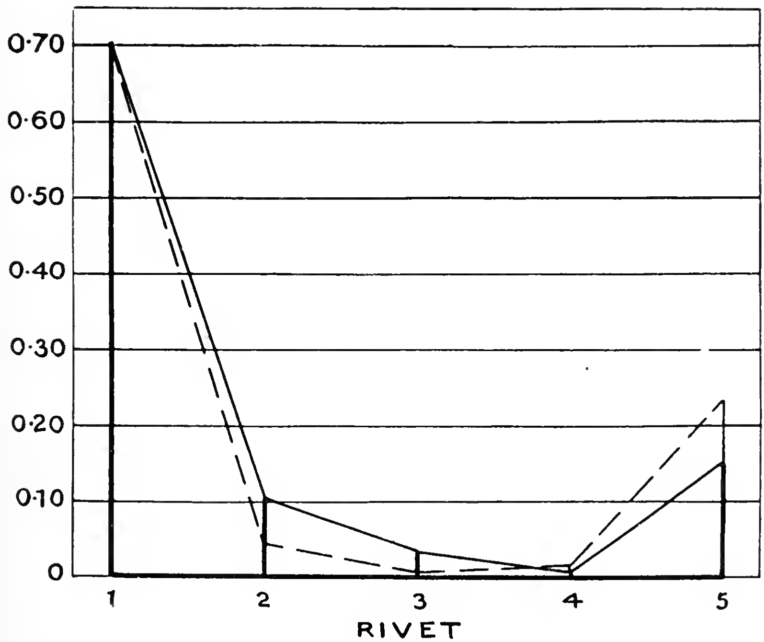
e = Experimental.
t = Theoretical.

the difference increasing with the value of C. This is entirely borne out by the experimental results as shown in Table IX, the percentage taken by the first rivets being respectively 70.7, 63.8, and 50.0 for the three specimens. The loads taken by the other rivets also agree in general with the theoretical results.

It was shown in the last section that K for 3/4-inch rivets is equal to 0.18×10^{-4} F. For a load of 16,000 pounds this gives $K = 0.29$. If, as surmised above, a small difference in the length of the rivets does not alter K, the above value ought to give figures which agree with the experimental results. The two cover plates, however, did not in any of the specimens receive exactly the same loads, and allowance must be made for this, as explained in §3, Part I. The actual ratio of the loads taken by the two cover plates was not constant at each section. This could be

allowed for if necessary, but the effect of the correction is, in any case, so small that it will be quite sufficient to take mean values. The mean values of $\frac{1}{s}$ in D, E, and F were 0.595, 0.574, and 0.510 respectively. Thus, allowing for these, the values of C become 4.04 and 3.02 for D and E respectively, remaining practically unchanged for F'. By substituting these values in the equations of Part I and taking $K = 0.29$, the figures in the rows marked t in Table IX were obtained, and the results are shown with the experimental results in Figs. 21 to 23. It will be seen that the agreement is fairly close. It is almost exact for the first rivets,

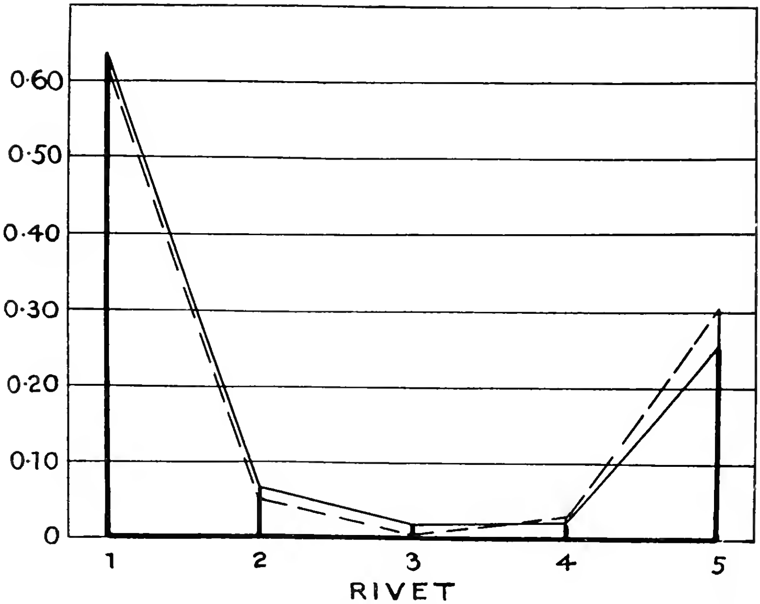
FIG. 21.



Specimen D.

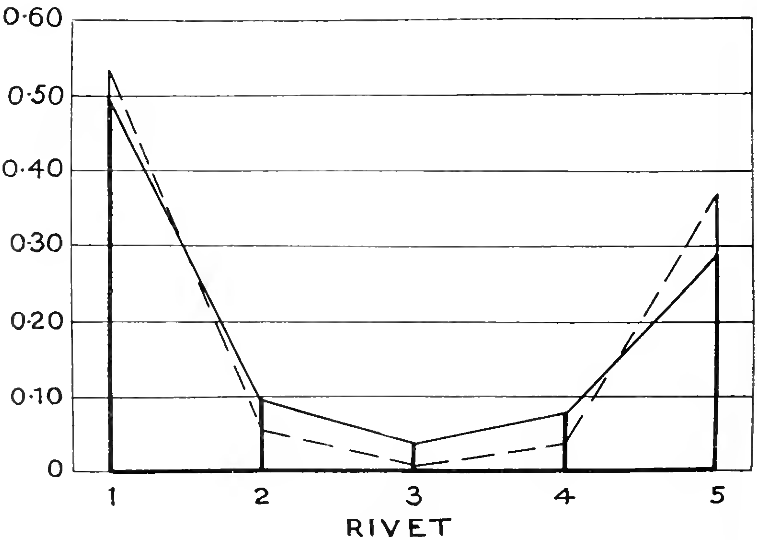
which are the most important. The fifth rivets, however, take less than the theoretical loads in each case, the difference being distributed among the middle rivets. This may arise from actual differences in K for the different rivets or from bending, but, considering the nature of the specimens and the probable irregularities in setting of the rivets, the agreement may be regarded as satisfactory, especially when it is remembered that the value of K used

FIG. 22.



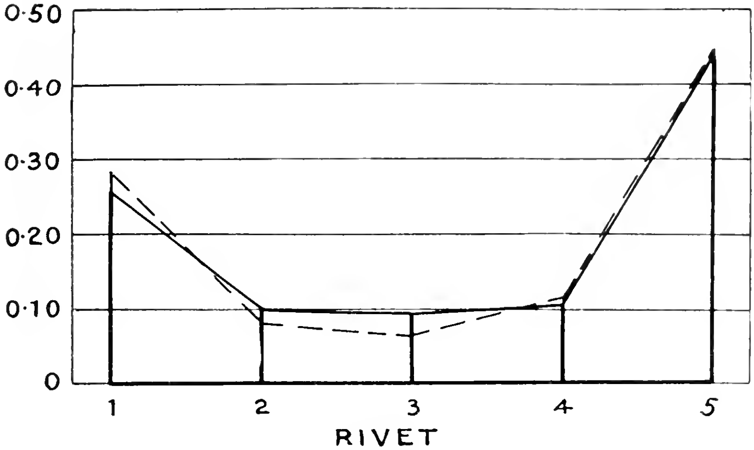
Specimen E.

FIG. 23.



Specimen F′.

FIG. 24.



Specimen F.

was obtained from a single set of experiments on another specimen.

F was the only specimen tested in which the width of the middle plate was variable. The theoretical equations for this specimen are of the type given in Part I, §4. η, the coefficient depending upon the variable width of the plates between each pair of rivets, is so near to unity that it may be neglected. The values of the terms in $2\Sigma\frac{a_c}{a_1}$ are

$$\frac{2a_c}{a_1}=\frac{2\times 3}{12.32}=0.487,$$
$$\frac{2a_c}{a_2}=\frac{2\times 3}{10.2}=0.588,$$
$$\frac{2a_c}{a_3}=\frac{2\times 3}{8.08}=0.743,$$
$$\frac{2a_c}{a_4}=\frac{2\times 3}{5.96}=1.007.$$

Thus

$$2\sum_1^4\frac{a_c}{a}=2.825,\ 2\sum_2^4\frac{a_c}{a}=2.338,\ 2\sum_3^4\frac{a_c}{a}=1.750$$

and $2\sum_4^4\frac{a_c}{a}=1.007$, and the equations for the loads taken by the various rivets, Part I, §4, p. 589, taking $K=0.29$, become

7.405	5.628	4.040	2.297	3.115
5.628	5.918	4.040	2.297	2.628
4.040	4.040	4.330	2.297	2.040
2.297	2.297	2.297	2.587	1.297

The solution of these equations gives the results displayed in Table IX and shown by the dotted lines in Fig. 24. There is again a remarkable agreement between the theoretical and experimental results.

The two specimens F and F′ are similar to the ordinary types of end connections of riveted bridge members, and the results show that the widening of the gusset plate results in far less load being carried by the first rivet and also increases the proportion of the load taken by the middle rivets from 21.1 per cent. to 30.3 per cent. of the total load, giving a more even partition of the load.

§6. *General Conclusions.*

The results of the experiments carried out up to the present have now been given and analyzed, and it only remains to see what general conclusions can be drawn from them. In the first place, all the experiments are in remarkable agreement with the theory advanced in Part I, especially when it is taken into consideration that the specimens were ordinary shop products, and show that it is possible to predict, in general, the way in which the load will be divided among the rivets in any form of joint.

Only the specimen with ½-inch rivets was carried beyond the working load, but the regularity of its action showed that the partition of load obeyed the same laws at all loads up to that causing permanent deformation of the plates or rivets. In every specimen and at all loads the first and fifth rivets took by far the greater part of the total load, the actual proportion decreasing gradually as the load increased. For example, in the specimen with ½-inch rivets, the first and fifth rivets carried 83.5 per cent. of the total load at a load of 10,000 pounds, and this decreased to 70.0 per cent. at a load of 30,000 pounds. The latter load corresponds to an average stress of about 12,650 pounds per square inch of actual rivet section, or 15,280 pounds per square inch of nominal rivet section. This would usually be taken as the shearing stress on all the rivets, but actually the end rivets, if, as there seems little doubt, the rivets were in shear and not holding by friction, were each under an average shear stress of 22,150 pounds per square inch, while the third rivet at the same load took only 3.2 per cent., corresponding to an average shear stress of only 2020 pounds per square inch. Thus in joints having

several rows each containing an equal number of rivets and designed in the usual manner, *i.e.*, allowing the average load per square inch of rivet section to be equal to the working stress in shear of the rivet material, the rivets in the end rows must carry stresses far above the allowable working stress. That this will not be remedied by increasing the number of rows of rivets was shown in Part I, §2.

The above refers to the specimens in which the cover plates were of the correct thickness; *i.e.*, each half as thick as the middle plate. If they are thicker, the first rivet takes an even greater proportion of the load, the proportion increasing with increased thickness. This was shown theoretically in Part I and experimentally on the specimens D, E and F′. Specimens B, D, E and F′ all had the same diameter of rivet. In specimen B, in which the cover plates were of correct thickness, the first and fifth rivets took 88.1 per cent. of the load at a load of 16,000 pounds. In specimens D, E and F at the same load they carried 86.2 per cent., 89.7 per cent. and 78.9 per cent. of the total load respectively, but of these the first rivets carried respectively 70.7 per cent., 63.8 per cent. and 50 per cent. of the total load. Specimen F, in which the middle plate was of varying width, illustrated the action in members riveted to a gusset plate, and it was found that the varying width of plate resulted in a rather more even distribution of stress, the first and fifth rivets carrying only 69.7 per cent. of the load, as compared with 78.9 per cent. when the middle plate was cut down to uniform width.

It must be noted that in all the specimens tested the ratio of width of cover plate to pitch of rivets was the same, 3/4. Now it was shown in §4 that K probably varies as the width of cover plate divided by the pitch of the rivets; thus, with a smaller pitch or wider plates, K would be increased, and the effect of this would be to make the partition of the load rather more uniform. But, as stated above, a large variation of K only causes a comparatively small alteration in the percentage of the load carried by the end rivets. For example, in the specimen A a change of K from 0.485 to 1.3 only altered the load carried by each of these rivets from 40.7 per cent. to 35 per cent., and the alteration for a given change becomes less and less as the values of K increase. Thus the effect of change of pitch or breadth of cover is not likely to be very great, except possibly in splices containing a number of

rivets in each row. However, further experiments are needed in order that a general law may be found for the value of K. When this is determined it will be possible to predetermine the exact partition of load in any proposed joint, and this will enable the joint to be designed in the most efficient manner. A very good approximation, sufficient for most purposes, may, however, be obtained from the data already given, since the general manner of partition of load is the same for all values of K. It would require too much space to illustrate this further here, but the examples given in Part I show clearly the method of procedure.

The writer has already in hand further experiments on the variation of K in different types of joints and also experiments designed to show the part, if any, played by friction in riveted joints.

§7. *Summary and Conclusion.*

The following is a summary of the principal contents of the present paper:

1. It is shown that a riveted joint may be considered as a statically indeterminate structure, and that a series of equations may be obtained for any joint by means of the Principle of Least Work, giving the loads carried by each of the rivets in terms of a quantity K, which depends upon the manner in which work is stored in, or by the action of, the rivets.

2. This theory is applied to various types of joints, and the modifying effects of non-uniform distribution of stress in the plates, unequal partition of the load between the two cover plates, and a difference in the modulus of elasticity of the middle plate and the cover plates are also considered.

3. It is shown experimentally that extensometer measurements on the outer surfaces of the cover plates of a riveted joint are sufficient for the determination of the mean stresses in the plates, and that the partition of the load among the rivets may be determined from such measurements. It is also shown that, at any rate after the first few loadings, the distribution of strain in the plates of a joint is not altered by repeated loadings.

4. It appears from 3 that if there is any frictional hold between the plates, it acts only over those portions in the immediate neighborhood of the rivets. All the experiments tend to show that friction does not play an important part, but further experiments are necessary on this point.

5. Experiments made on a number of specimens having a single line of rivets and loaded in tension give results in close agreement with the theoretical considerations. They also show that the longitudinal stresses in a portion of the cover plate between two consecutive rivets are a minimum along the line of rivets, rising to a maximum at the edges of the plates.

6. The experiments show that the value of K for a joint having a given ratio of width of cover plate to rivet pitch and a given number of rivets varies approximately directly as the load and inversely as the area of the rivets. An empirical rule is given for its value in joints similar to the experimental specimens, but a more general rule cannot be given until further experiments have been made. A theoretical estimate is made of the value of K for a rivet acting in shear, and the result is shown to be within the range of the experimental values.

7. Both the experimental results and the theoretical deductions show that:—

(*a*) in a double-cover butt joint having a single line of rivets, the two end rivets and the two rivets on each side of the junction of the middle plates take by far the greater part of the load at all loads within that causing permanent deformation of the plates or rivets, the actual proportion decreasing slowly as the load increases;

(*b*) if, in such joints, the total area of cross-section of the cover plates is equal to that of the middle plates, these four rivets take equal loads, but if it is greater the end rivets take greater loads than the others, the difference increasing as the area of the cross-section of the cover plates increases;

(*c*) if two plates of uniform width and equal thickness are connected by a single line of rivets to opposite sides of a gusset plate of uniform width, the first and last rivets take the greater part of the load, but if the gusset plate increases in width from the first to the last rivets, the partition of load is more uniform.

The results already obtained allow the general manner of partition of load in any riveted joint, in which there is no eccentricity of connection, to be estimated, and it is hoped that, when further experiments have given general laws for the value of K, it will be possible to predetermine the exact load that will be carried by each rivet. The practical value of this is obvious.

In conclusion, the writer wishes to thank Prof. H. M. Mackay and Prof. E. Brown for their personal interest and advice, and Mr. S. D. Macnab for his valuable assistance in the experimental part of the work.

McGill University,
August, 1916

Maintenance Cost of Four-cylinder Engines. F. E. WATTS. (*Society of Automobile Engineers Bulletin*, vol. x, No. 5, August, 1916.)—It is an axiom in all mechanical work that the less complicated a machine is, the lower must be its maintenance cost. This is apparent enough in a comparison of the four-cylinder engine with other types. It is more accessible and has fewer parts in proportion to its fewer cylinders. Repairs are consequently not only less frequent but are less costly to make. The fuel efficiency is also fundamentally better. In any type of fuel distribution used in motor cars to-day, the division of the gaseous stream decreases efficiency. The simple cylinder is the most economical type; and the fuel efficiency decreases as the number of cylinders increases. Certified tests made on carefully tuned and adjusted cars are often misleading, and the result in the hands of the user is the only real criterion.

Designers of multi-cylinder engines are now at work on much smaller units utilizing very high compression. This method was tried out about ten years ago and finally abandoned, but with the increased technical skill available at the present time, and the smaller cylinder sizes, it is possible that something can be accomplished. It is, however, doubtful just how much can be done with our present motor car fuel, for the gasoline now available tends to partake more and more of the nature of kerosene, and does not lend itself exceptionally well to high compression. Recent tests have shown that it takes a considerable increase in compression to insure a slight increase in the mean effective pressure, particularly at the lower speeds. It was also found that the engine with high compression does not operate as smoothly as the one with the lower compression, while engines having very high compression may show better fuel economy during tests in the hands of careful users, it does not promise to prove satisfactory for general use.

QUANTITATIVE MEASUREMENTS AT WASHINGTON ON THE SIGNALS FROM THE GERMAN RADIO STATIONS AT NAUEN AND EILVESE.*

BY

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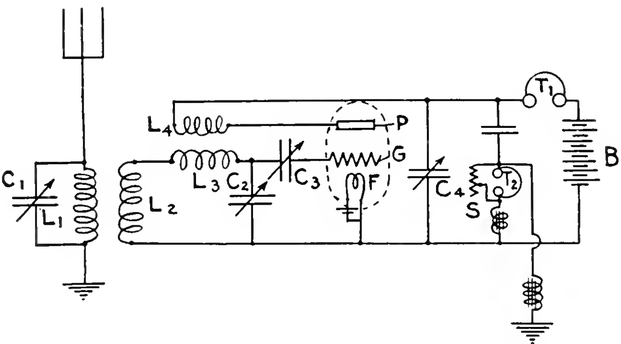
SINCE September, 1914, the strength of the signals received from Nauen and Eilvese has been measured almost daily at the U. S. Naval Radio Laboratory at the Bureau of Standards.

The antenna at the laboratory has an effective height of thirty metres. It is a flat top, 450 feet long, having two wires about two metres apart, 59 metres high at one end and 17 metres at the other. Its resistance at the longer wave-lengths is considerably lower than the one formerly used.

The circuits used for reception are shown in Fig. 1. The

FIG. 1.



detector is the de Forest audion, with an extra coupling, L_3L_4, for producing local oscillations. The current-flow in the audion is naturally unstable, as in the Poulsen arc. This instability tends to produce oscillations, the period of which is determined by the circuit $L_2L_3C_2$. These oscillations are strengthened in the circuit PC_4F, and this increased energy is returned to the circuit $L_2L_3C_2$ through the coupling L_3L_4, thus sustaining the original oscillations, which otherwise tend to break.

* Communicated by the Author.

In the reception of signals from stations sending out continuous oscillations from a high-frequency machine or arc, the receiving audion circuit is so adjusted that the local audion oscillations are slightly out of tune with the incoming oscillations. The combination of the two sets of oscillations produces beats of a frequency which can be heard in the receiving telephones. The pitch of the beats can be adjusted at will by regulating the amount of detuning.

The strength of signal is measured by the shunted telephone method, in which a non-inductive shunt s is placed across the telephones T_2 of the audion and reduced until the signals just remain audible. If I is the value of the current-pulses in the unshunted telephones, and I_0 the current which is just audible,

$$\frac{I}{I_0} = \frac{t+s}{s}$$

where t is the effective telephone resistance for the given beat frequency and s the resistance of the shunt which just permits signals to be heard. The ratio $\frac{I}{I_0}$ is called the audibility of the signal. In an experiment described elsewhere [1] it has been shown that the audibility in the oscillating audion is proportional to the current in the receiving antenna, instead of to the square of the current, as in the electrolytic, the crystal contact detector, and the non-oscillating audion.

The oscillating audion is calibrated for quantitative measurements by comparing the audibility of a given signal with the deflection produced on a galvanometer attached to a silicon detector by the same signal.[2] The audion and silicon can be alternately connected to the secondary circuit by a double-throw switch, the circuit and coupling being adjusted in each case for maximum effect. Just before each experiment the silicon detector is calibrated by comparison with a thermo-element in the artificial antenna. It has been found that when the circuits are properly adjusted for each individual bulb practically all de Forest bulbs which are not evidently imperfect give about the

[1] *Journal Washn. Acad.*, 6, p. 81, 1916.

[2] On account of atmospheric disturbances this calibration is made on an artificial antenna having the same constants as the real antenna, the signals being produced by a second oscillating audion in the laboratory.

same sensitiveness. The sensitiveness, however, varies very greatly for slight changes of adjustment, so for measurement purposes it is of the greatest importance that the adjustment be made in exactly the same way. One of the most reliable methods is to tune the antenna and closed circuits with loose coupling and then, leaving the antenna unchanged, bring up the secondary and retune it at the best coupling. Using Baldwin telephones of 2000 ohms direct-current resistance and a sensitiveness of 5×10^{-10} ampères at 1000 cycles for normal ears, the least audible signal represents about 1.5×10^{-15} watts in the receiving system. The audibility increases as the square-root of the received energy. The proper adjustment of the main coupling appears to make the sensibility within wide limits practically independent of the resistance of the secondary and of the wave-length.

The results of the observations on Nauen and Eilvese from January 1, 1916, to July 1, 1916, are shown in the curves of Fig. 2. The earlier observations are not given, since, on account of changes in the methods of observation, they are not considered properly comparable with the later ones.

The most striking thing about these curves is their remarkable variability, the received current varying from 1×10^{-7} ampères to 80×10^{-7} ampères; that is, from about 25 audibility to more than 2000 audibility, with the method of adjustment used. The cause of these variations is not entirely clear. In some earlier experiments [3] it was thought that probably the variations were, to a considerable extent at least, due to observational errors, but it seems now fairly certain that under normal conditions of atmospheric disturbances the limits of observational error are 20 to 30 per cent., while in extreme cases the limit may be two to one, which will not go far toward explaining these large changes in observed current.

It is now believed that the variation in intensity is due, for the most part, to an irregular reflection or possibly refraction in the upper atmosphere, which brings to the receiving station energy in addition to that which travels along close to the surface of the earth. It is also probable that there is a certain amount of absorption due to the ionization of the atmosphere. Marconi has stated that between Glace Bay and Clifden, Ireland, the signals are weaker during the presence of marked low barom-

[3] *Bulletin Bureau of Standards,* 7, p. 315, 1911.

eter areas between the stations, and the present work seems to support his statements to some extent. There seems to be some reason to believe that regions where atmospheric disturbances are pronounced may be also regions of absorption.

Professor Sommerfeld and his students have developed a theory of the transmission of waves over a good conducting surface like salt water, which may be approximately expressed by the following formula:[4]

$$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R} \cdot e^{-\frac{0.0019 \cdot d}{\sqrt{\lambda}}} \tag{1}$$

where I_r is the current in the receiving antenna, I_s the current in the sending antenna, h_1 and h_2 the respective heights of the centres of capacity of the sending and receiving antennas, λ the wave-length, d the distance, and R the resistance of the receiving system. The currents are expressed in ampères and the lengths in kilometres. The first term of this expression is derived from the Hertzian theory. The exponential term represents the falling off in intensity due to the failure of the waves to follow the curvature of the earth. Equation (1) takes no account of the possible return of some of this lost energy from the upper atmosphere, and it seems probable that this equation is fairly correct for the signals on the worst days. The formula for received current used by the Navy Department makes use of the same Hertzian term as Equation (1), but employs an exponential term which was derived empirically from the observations made during the long-distance tests between Brant Rock and the cruisers *Salem* and *Birmingham* in 1909 and 1910.[5]

(2) Navy formula $$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R} \cdot e^{-\frac{0.0015 \cdot d}{\sqrt{\lambda}}}$$

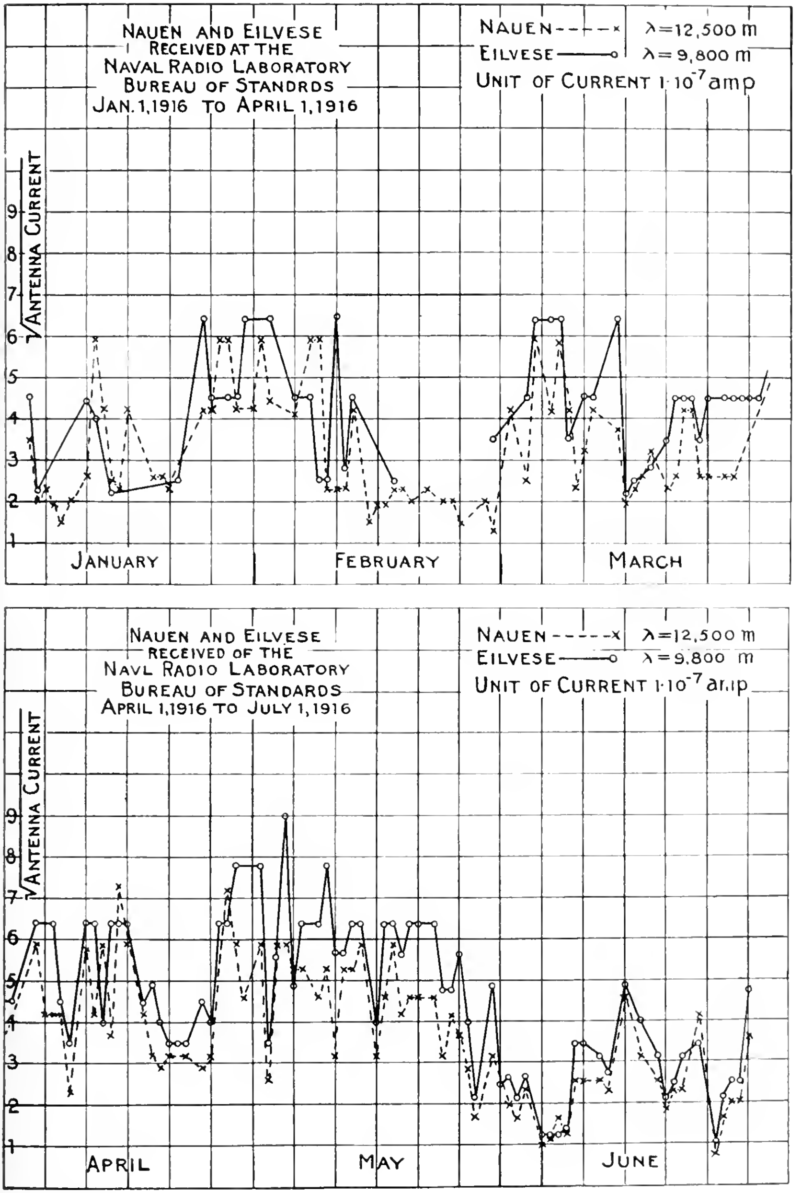
This formula was intended to represent the average value of received current over salt water in the day time, and appears, so far as can be certainly determined, to give results which are correct within the limits of observational error, at least up to 3600 nautical miles.

The observations shown in the curves of Fig. 2 were taken

[4] A. Sommerfeld, *Ann. der Phys.*, **28**, p. 665. 1900; also H. March, *Ibid.*, **37**, p. 29. 1912; W. von Rybczynski, *Ibid.*, **41**, p. 191, 193; and J. Zenneck, "Lehrbuch der drahtlosen Telegraphie," p. 294.

[5] *Bulletin Bureau of Standards*, **7**, p. 35, 1911, Reprint 159, and *Bulletin Bureau of Standards*, **11**, p. 69, 1914, Reprint 226.

FIG. 2.


NAUEN AND EILVESE
RECEIVED AT THE
NAVAL RADIO LABORATORY
BUREAU OF STANDRDS
JAN. 1, 1916 TO APRIL 1, 1916
NAUEN ----x λ=12,500 m
EILVESE ——o λ=9,800 m
UNIT OF CURRENT 1·10⁻⁷ amp
√ANTENNA CURRENT
1
2
3
4
5
6
7
8
9
JANUARY
FEBRUARY
MARCH
NAUEN AND EILVESE
RECEIVED OF THE
NAVL RADIO LABORATORY
BUREAU OF STANDARDS
APRIL 1, 1916 TO JULY 1, 1916
NAUEN ----x λ=12,500 m
EILVESE ——o λ=9,800 m
UNIT OF CURRENT 1·10⁻⁷ amp
√ANTENNA CURRENT
1
2
3
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APRIL
MAY
JUNE

in general between the hours of 9 and 11 A.M., Washington time, and therefore represent the signals transmitted from Germany to America when daylight covers the whole path of transmission. After sunset in Germany,—that is, when the path of the signals lies partly in darkness and partly in daylight,—the intensity of reception is often very much weakened, as though there were a backward reflection from the shadow wall.

Very few observations have been taken during the hours when the whole path of the signals lies in darkness, but these indicate that the variation between day and night at these wave-lengths is not greater than that noted on different days.[6]

The average observed received current for each month is given in the table, as well as the values calculated from the Sommerfeld theoretical formula and from the Navy formula.

The currents as calculated from the theoretical formula are seen to be less than one-tenth of the average observed values, but if the square-roots of the theoretical values of current be compared with the observed curves it is found that some of the minimum points are in fairly good agreement. The formula developed by H. M. Macdonald[7] would apparently give even smaller values than Equation (1).

The table shows that the signals during April and May were stronger even than during the winter, and that this period of strong signals was followed by a very decided drop in June. These seasonal variations, as well as the daily variations shown in Fig. 2, are almost certainly connected with atmospheric changes, but these may to a considerable extent take place at heights above the ordinary range of meteorological observations. It is possible that the decrease in intensity in early summer may be connected with the southward movement of the low-pressure area of the North Atlantic. It is known that the seasonal changes at great heights lag behind the corresponding surface changes.[8] The

[6] The well-known increase in strength of night signals is a function both of the wave-length and of the distance. Wave-lengths of 10,000 and 12,000 metres will probably begin to show distinct strengthening at night at a distance of about 5000 miles.

[7] See Eccles's "Wireless Telegraphy," p. 161, 1916.

[8] See W. R. Blair, *Bulletin of the Mt. Weather Observatory,* U. S. Weather Bureau, vol. 6, part 4, p. 179, 1914.

study of these relationships, while it is of great interest, must wait until more observations are available.

MONTHLY AVERAGES OF OBSERVED RECEIVED CURRENT.

1916	From Nauen, ampères	From Eilvese, ampères
January	$13.2.10^{-7}$	$19.5.10^{-7}$
February	10.4	18.2
March	12.6	20.8
April	22.4	29.0
May	21.6	33.8
June	6.2	8.5
General Average	14.4	21.6

CALCULATED.

From equation (1)	0.95	1.91
From equation (2)	14.3	22.2

DATA FOR CALCULATION.

	I_s Ampères	h_1 Metres	h_2 Metres	d Kilo-metres	λ Metres	R Ohms	$e^{-\frac{0.0019d}{\sqrt[3]{\lambda}}}$	$e^{-\frac{0.0015d}{\sqrt{\lambda}}}$
Nauen	150*	150	30	6650	12500	124	0.0039	0.058
Eilvese	140*	150	30	6100	9800	93	0.0045	0.052

* As given in 1914.

U. S. Naval Radiotelegraphic Laboratory,
August, 1916.

Heat Losses Through Galvanized Roofing. ANON. (*The Iron Age*, vol. 98, No. 8, August 24, 1916.)—Loss of heat through a roof of galvanized steel sheets is less than through roofing consisting of cement and fibrous material compressed to sheets about 1/4 inch in thickness, according to experiments made last year by the National Physical Laboratory at Teddington, England. A model hut was built up of walls of cork slabs, 2 inches thick, and a roof of the new material or of galvanized sheet iron. The air inside was heated by electrical resistance, which was not allowed to get sufficiently hot to set up appreciable radiation, and the air was agitated by a fan. The air temperature inside differed by 30° F. contrary to expectation, the heat losses through the cement, measured per square foot, were 20 per cent. greater than through metal, the reason being that the emissivity loss from the surface and not from the thermal conductivity of the material, is the decisive factor. When the iron was painted black the heat transmission increased, becoming equal to that of the cement; when the cement slabs were painted with aluminum they behaved like the iron.

Allowance, Tolerance and Limit. D. T. HAMILTON. (*Machinery,* vol. 25, No. 2, October, 1916.)—In manufacturing operations the terms "allowance," "tolerance," and "limit" are frequently used interchangeably, although as a matter of fact they represent different quantities. *Allowance* is the difference between the diameter of the shaft and the hole it enters to allow for various classes of fits, such as drive, push, running, force, etc. *Tolerance* is the difference between the maximum and minimum diameters of either the shaft or the hole necessary to tolerate unavoidable imperfections in workmanship. *Limit* is the amount set above or below the nominal diameters of the shaft or the hole in order to limit the amount of error that can be tolerated.

For example, suppose it is necessary to make a shaft with a good running fit in a bushing. The difference between the nominal diameters of the shaft and hole is 0.002 inch. This is known as the allowance. The limits on the diameters of the hole and shaft, respectively, are -0.00025 inch, $+0.0005$ inch, and ± 0.00075 inch, so that the tolerance on the hole is 0.00075 inch, and on the shaft, 0.0015 inch. For a nominal hole of 1 inch and shaft 0.998 inch, this gives a maximum hole of 1.0005 inch and a minimum shaft of 0.99725 inch, a difference of 0.00325 inch; and a minimum hole of 0.99975 inch and a maximum shaft of 0.99875 inch, a difference of 0.001 inch. From this it will be seen that the allowance between the shaft and hole is what is desired but seldom obtained.

The Magnetic Shielding of Large Spaces. E. WILSON and J. W. NICHOLSON. (*Proceedings of The Royal Society,* Series A; vol. 92, No. A-644, September 1, 1916.) The magnetic shielding of a large space is a problem wholly different in practice from that of a small space, and in view of important applications, the efficiency to which such shielding can be raised is a matter of importance. Considerations of mobility of the apparatus and weight of iron required necessitate the solution of the problem of maximum shielding for a given weight of iron, and more than two shells, together with an examination of the utility of lamination.

By the use of 1273 kilograms of high permeability dynamo magnet steel, a field of order so low as $3\ (10)^{-3}$ has been obtained in a space of 30 centimeters radius, an accurate method of measurement designed for fields of lower order being employed. The leakage through air spaces in a magnetic shield has been studied and found to be more important than is usually supposed. Although polarization of the shells still exists to a small extent, it is not of sufficient magnitude to effect any of the conclusions which have been reached. The leakage field can in fact be completely isolated from other fields. It is now possible to examine the behavior of iron under practically no magnetic force.

THE VITAL RELATION OF TRAIN CONTROL TO THE VALUE OF STEAM AND ELECTRIC RAILWAY PROPERTIES.*

BY

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Member of the Institute.

(*Continued from page 462*)

Piston travel, where the type of rigging permits it to vary, is a function of the *time* or duration of brake application, as well as of the cylinder pressure. For a condition of four inches false piston travel, as shown in Fig. 11, dotted curve *A*, in the upper figure, represents more nearly what the variation in travel with cylinder pressure would be for an actual brake application, for the piston travel will not lengthen out immediately. It takes a certain period of time for the jolting of the cars and trucks to assist the brake shoes to pull down on the wheel treads, as illustrated in Fig. 10, and thereby lengthen the piston travel. This is significant, because the shocks occur in the early stages of a brake application. Curve *B* in the lower figure shows what the condition portrayed by curve *A* means in the way of high cylinder pressures for light brake pipe reductions. At the point (6 pounds brake pipe reduction) where the brake with the ideal condition of no false piston travel whatever is just starting to become effective the single-shoe brake rigging with four inches false piston travel has about 21 pounds cylinder pressure, as shown by curve *B*. Is there any wonder that shocks occur in the long passenger trains of to-day? It is necessary to make at least a six- or seven-pound brake pipe reduction in order to insure that all triple valves apply and that sufficient differential may be set up to release them when desired. In the attempt to put the brakes on lightly and avoid shocks, insufficient reductions are made, with the inevitable result of stuck brakes.

All these things may be summed up in the following:

In modern heavy passenger train service, the single-shoe type

* Presented at a meeting of the Mechanical and Engineering Section held Thursday, April 27, 1916.

of foundation brake gear with inherent false piston travel is responsible for:

1. Rough handling of trains in:
    - (*a*) Starting—violent "taking of slack" necessary to get train under way.
    - (*b*) Slowing down.
    - (*c*) Stopping.

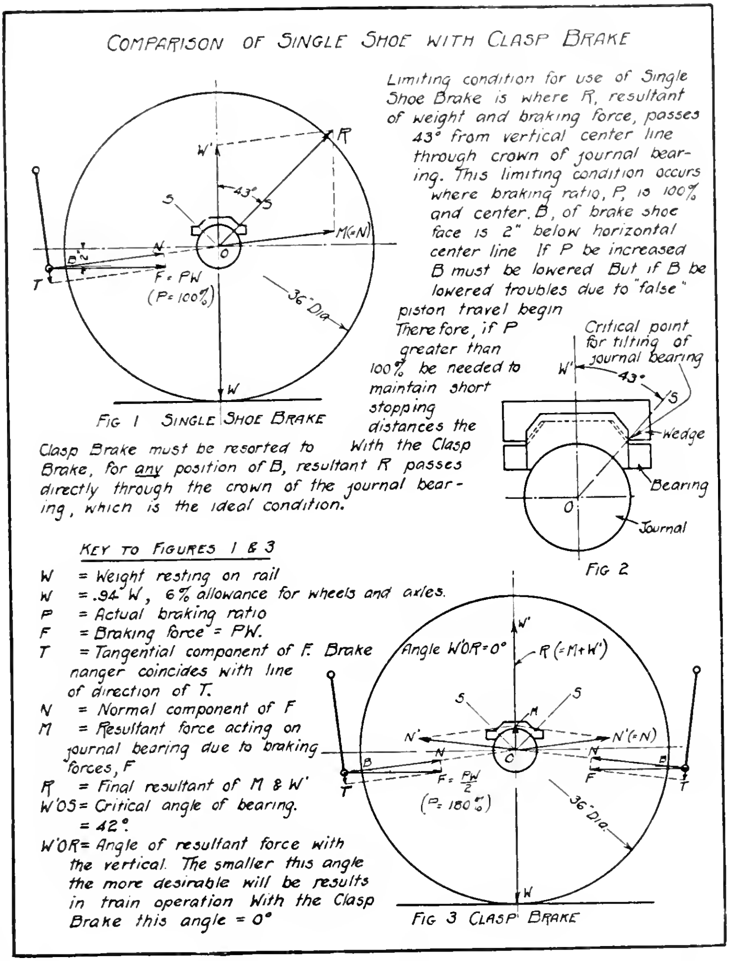
2. Inability to "make the time" because of:
    - (*a*) Hard pulling train—due to dragging brake shoes and stuck brakes.
    - (*b*) Long-drawn-out stops—"dribbling on" brakes in attempt to avoid shocks.
    - (*c*) Delays due to hot journals, stuck brakes, flat wheels, and damage arising from shocks.

3. Unwarranted expense in:
    - (*a*) Excessive fuel and water consumption.
    - (*b*) Reduced capacity of engine.
    - (*c*) Slid flat wheels due to shocks, stuck brakes, and shifting of weight from one pair of wheels to another.
    - (*d*) Damage arising from shocks, even to the extent of break-in-twos.
    - (*e*) Hot journals.
    - (*f*) Burned brake shoes and brake heads.

Obviously, the way to cure these troubles is not to dally with the effects, but to strike back to the underlying causes by applying a suitably designed foundation brake gear of the two-shoe-per-wheel or "clasp" type. Fig. 12 illustrates the part the single-shoe brake plays in giving journal trouble, and the remedy the clasp brake affords. It proves that the clasp brake should be employed whenever it is necessary to exceed a braking ratio of 100 per cent. for either emergency or service applications. And if the point is taken as here established for the failure of the single-shoe brake to be "equal to the job," the need for the clasp brake on account of the overloaded brake shoe will have been cared for long before it arises. This applies to passenger service only, for in freight service, where a comparatively low braking ratio is used,

the absolute value of the brake shoe pressures may, nevertheless, be such as to warrant the use of two shoes per wheel in order to divide the load and reduce brake shoe costs.

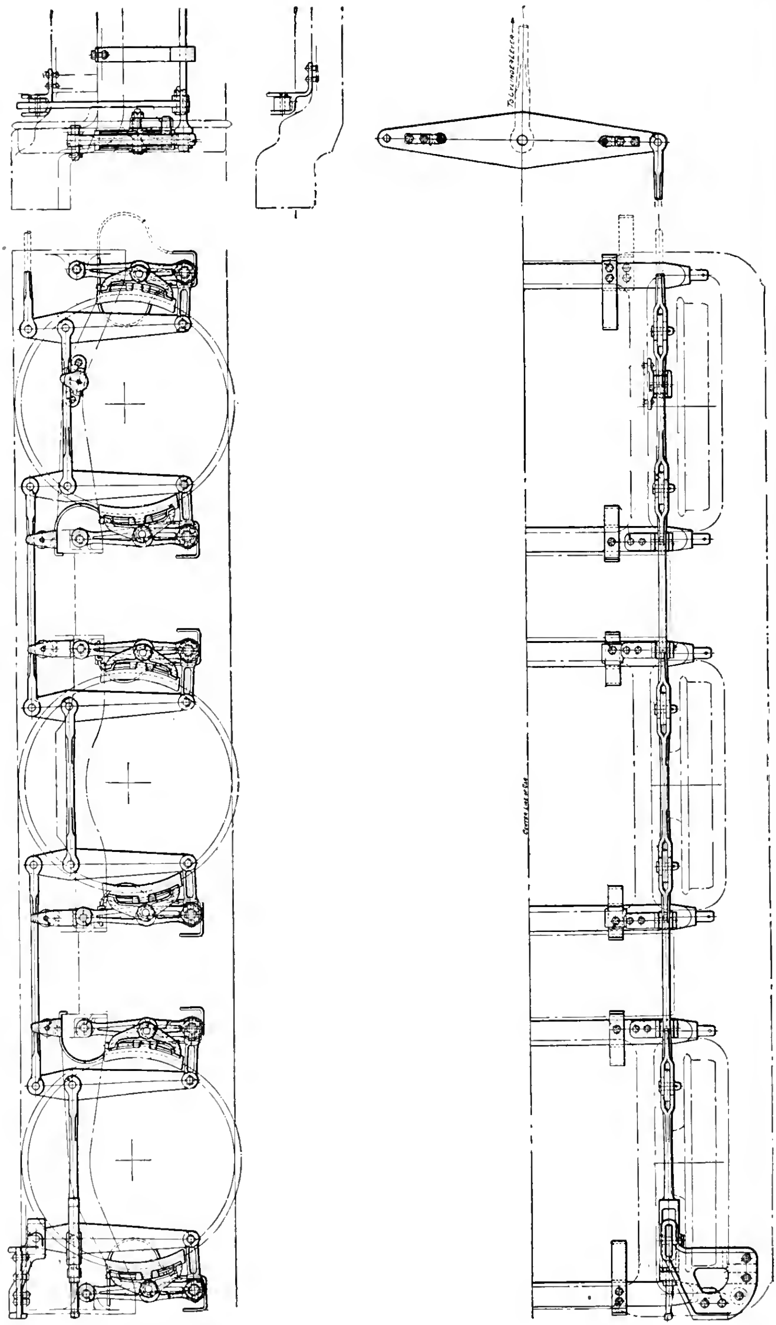
FIG. 12.



The clasp brake should always be installed when, in order to maintain short stopping distances, it is necessary to use an effective braking ratio of 100 per cent. or more.

For two reasons the foregoing list of troubles, occurring in passenger service, do not appear in freight service: First, the braking ratio is limited to 80 per cent.; and, second, the type of

FIG. 13.



A suitably designed clasp brake for a six-wheel truck.
Proper truck construction must contribute with suitable clasp brake design in the elimination of false piston travel.

truck generally used does not permit relative movement between the truck frame and wheel.

In summing up, it may be said that a well-designed clasp-brake rigging, such as that shown in Fig. 13, eliminates the single-shoe brake evils above scheduled as no other device can possibly do. A more direct comparison may be drawn up between the single shoe and clasp types of brake gear by saying that with the clasp brake it is possible to have:

1. Shorter stops in emergency, due to reduced brake shoe duty.
2. Reduced brake shoe wear.
3. Reduced brake shoe maintenance.
4. No brake shoe dragging—reduced train resistances.
5. Longer trains handled with less loss of time, using same motive power equipment.
6. Fewer delays.
7. Smoother stops.
8. More accurate stops.
9. Fewer slid flat wheels, due to shocks, stuck brakes, and the transfer of load from one pair of wheels to another.
10. Fewer stuck brakes.
11. Fewer hot journal bearings.

BRAKE CYLINDER PRESSURE REGULATOR.

In order to have some measure of relief from the evils attendant upon the use of the single-shoe brake, pending the accumulation of the funds required in order to meet the sometimes very great expense of remodelling trucks to provide for a suitable clasp brake rigging, a device has been designed which makes the auxiliary reservoir volume a function of the piston travel. The brake application starts with an auxiliary of very much reduced size, which keeps down the brake cylinder pressures for light brake pipe reductions. The continued outward movement of the brake piston cuts in, at predetermined points, additional auxiliary volumes, finally giving full service pressure when the proper brake pipe reduction has been made. By so proportioning the parts it has been actually possible to get a characteristic curve of operation like that of curve *C* in Fig. 11. This provides, as is readily seen, even greater flexibility of brake operation than the clasp brake, but, of course, all the troubles and losses due to dragging brake shoes remain. This new device also arranges for the use of the first small auxil-

iary reservoir for all reapplications of the brake after a partial release, thereby cutting down the build-up in pressure on that retained in the cylinder and making smooth handling of long trains at low speeds much more certain.

GRADE SERVICE.

The problem afforded the operating departments of our railroads in the control of freight trains over mountain grades has always been far more difficult of satisfactory solution than the one arising in controlling passenger trains over similar districts. This is obviously because of the comparatively short length of passenger trains and their higher and *constant* braking ratio. The manufacture of the ton-mile will, therefore, occupy our attention in this phase of train control, and the empty and load freight brake will serve well as an introduction.

In grade service the advantages of the empty and load brake are at first glance more apparent than those had for level road service in the elimination of shocks. In descending a grade a certain percentage of the car weight is acting to accelerate it. This portion is equivalent to the percentage grade; that is, on a 2 per cent. grade 2 per cent. of the weight of a car on this grade is tending to accelerate it. Thus, if the car weighs 100,000 pounds, 2000 pounds is acting to accelerate it down the grade, and if this acceleration is not to take place, an equal opposing force must be brought into play to counteract the accelerating force.

The internal friction or resistance of the car provides a part of this opposing force. If this resistance be taken as 5 pounds per ton, a grade of $5/2000$, or 0.25 per cent., is required for the accelerating force to just equal the internal resistance. The 2 per cent. grade will cause a net accelerating force of $2.0-0.25=1.75$ per cent. of the car weight. It is as though the car was without any internal resistance whatever and stood upon a 1.75 per cent. grade. In figuring train control on grades it is necessary, therefore, to consider the internal resistance of cars, but this is neglected in figuring stops, for the reason that many tests have demonstrated that in bringing a car to a stop the internal resistance is just about equal to the force required to overcome the rotative energy of the wheels. In the subsequent formulæ given for stop distances you will notice that no allowance is made for either the rotative energy of the wheels or the internal resistance. In controlling a car on a

grade the rotative energy of the wheels does not change, practically speaking, and therefore the internal resistance operates in the direction of overcoming the accelerative force due to grade.

The retarding force set up by the brakes on a car is, in terms of car weight, equal to the braking ratio multiplied by the brake rigging efficiency and by the coefficient of brake shoe friction. Thus if a loaded car equipped with a single capacity brake has a braking ratio of 15 per cent., a rigging efficiency of 85 per cent., and a brake shoe friction of 15 per cent., the retarding force will be $0.15 \times 0.85 \times 0.15 = 0.01915$, or 1.9 per cent. of the car weight; that is, this retarding force will just equal a net accelerating force of 1.9 per cent., or one due to a grade of $1.9 + 0.25 = 2.15$ per cent., making the above allowance for internal resistance. But this would provide no reserve, no margin for safety or flexibility, because it would necessitate a constant cylinder pressure of 50 pounds (the basis for the braking ratio mentioned) all the way down the grade. Leakage, recharging, and the ability to come to a stop when desired would be quite uncared for. Considering time for recharging, length of train, reserve power for making a stop, leakage, etc., the cylinder pressure will average only 30 pounds for the entire descent of the grade. This means that the retarding force will be only 30/50 of 1.915, or 1.15 per cent., and the maximum grade corresponding, $1.15 + 0.25$, or 1.40 per cent. Making the same allowances for the empty and load brake, with its load braking ratio of 40 per cent., we find the maximum grade to be

$$G = 0.40 \times 0.85 \times 0.15 \times 30/50 + 0.25 = 3.31 \text{ per cent.}$$

You will notice that these limiting grades stand in approximately the same relation as do the braking ratios for the two types of brake. In each case approximately the same factor of safety holds good; that is to say, the empty and load brake is as safe on the 3.31 per cent. grade, as the single capacity brake is on the 1.40 per cent. grade, the only difference being an increase in air consumption of 17 per cent. for the empty and load brake.

The empty and load brake will control a train of loaded cars on a certain grade with only *one-half the air consumption* required by the single capacity brake with the same train on the same grade. This, in itself, shows how marvellously more flexible, more safe, and more economical the empty and load brake is.

The superior air consumption performance and reserve braking

force of the empty and load brake may be utilized in several ways. The speed of trains down grades may be increased, the speed restriction or limitation now passing from the brake to the question of wheel temperatures. The length of trains or the loading of cars may be increased, or all these increases made, and still leave the reserve in air supply and braking force comfortably great. And keep in mind the increased traffic capacity, reduced unit costs, and correspondingly increased net revenue that this means.

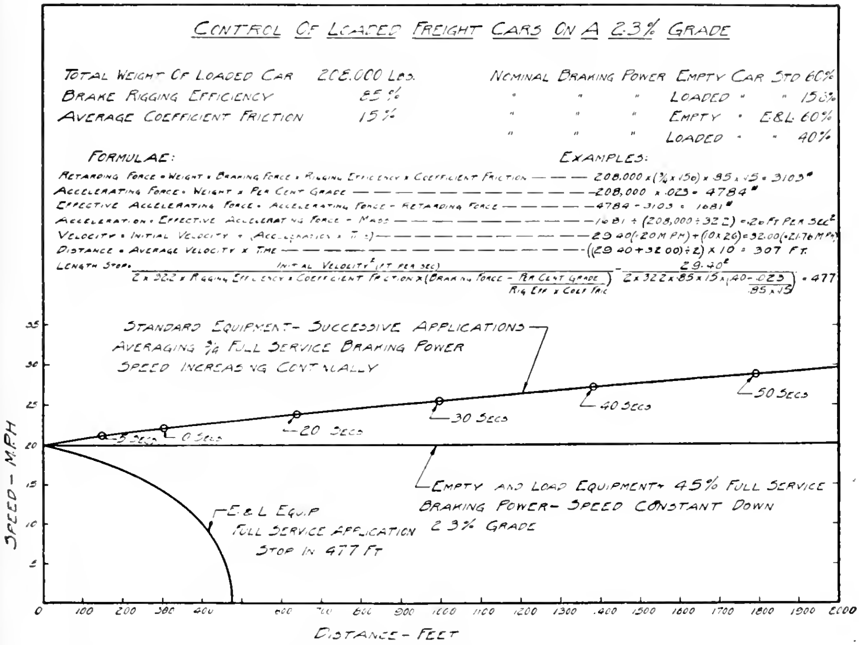
It will be appreciated that the reduction of 50 per cent. in air consumption in providing an equal braking force is of vast importance, that it is of *vital importance*, from a general operating standpoint, when it is remembered that brakes can be operated only by creating differentials on the one hand, and by replenishing the air brake system on the other. And it should be self-evident that to do either increases in difficulty with the increase in quantity of air required. We may say, roughly speaking, that this difficulty is in geometric proportion rather than arithmetic: that is, every time the quantity of air required is doubled, the difficulty will increase four times. Thus it will be seen that the larger the brake cylinders and, consequently, the auxiliary reservoirs that must be employed, the more difficult it becomes to release the brakes and to recharge the brake system. To those who have some idea of what a large auxiliary can absorb from the brake pipe and the effect of the resistance of a long brake pipe to the flow of large quantities of air, what is said above will only add emphasis to their present knowledge. But to those not familiar with or experienced in this problem it may be a revelation to say that with the present 10-inch freight brake equipment we have about reached the limit of our ability to efficiently operate brakes through the medium of compressed air, modern train lengths considered. With this statement properly digested, the importance of employing a brake which for a certain retarding force requires less than half the usual quantity of air will be appreciated.

In the matter of coming to a stop on a grade, the stop distance will be, other things being the same, inversely proportional to the braking ratio; that is, the loaded train equipped with the empty and load brake will stop in 15/40, or 37.5 per cent. of the distance required by the train with the single capacity brake.

Fig. 14 sums up in a graphic way the advantage the empty and load brake offers in grade work. The train equipped with the

single capacity brake, averaging 75 per cent. of the full service braking power (average cylinder pressure of 37.5 pounds—an assumption really too high), is running away on the 2.3 per cent. grade. In less than a minute's time its speed has increased from 20 to 30 miles per hour. The train equipped with the empty and load brake holds to the constant speed of 20 miles per hour with but 45 per cent of the full service braking power (average cylinder

FIG. 14.



Graphic summary of the advantages the empty and load freight brake offers for grade service. The train equipped with the single capacity brake is running away on the 2.3 per cent. grade. The empty and load brake provides such a braking reserve that the train can be stopped from 20 m.p.h. in short of 500 feet on this grade.

pressure of 22.5 pounds—a very conservative assumption), and its reserve braking force enables it to stop from this speed in less than 500 feet.

In discussing car weights a newly designed freight car was mentioned of 75,000 pounds empty and 315,000 pounds loaded weight, which a prominent southeastern railroad is going to put into service in the near future. Only two years ago on this road the maximum tonnage per train was 6000 tons in a maximum train

length of 80 cars. These limiting conditions were determined by the ability of the single capacity brake to control trains over the critical district—" the neck of the bottle " for the system—which has a grade of 1.5 per cent. With the introduction of a limited number of empty and load brakes the tonnage was raised to 8000 tons per train. The difficulty now passed to the question of adequate length of sidings to care for the traffic volume, which was overtaxing the capacity of this single-track line. To provide the proper number of sidings of suitable length would be to virtually double-track the road. The use of the new 240,000-pound capacity cars will, however, render possible the operation of trains of 15,000 tons, and postpone thereby the double-tracking of this line for 25 years, according to the estimate of the railroad people. Full credit must be given to the empty and load brake for this saving, for *it would be absolutely impossible to operate such trains of these cars without the use of an empty and load brake.*

VOLUMES OF AIR.

Particular mention has been made of the air volume limit in the capacity of the single capacity brake to control modern freight trains. As equipment, both freight and passenger, has become heavier and trains longer the volume of air required for control of these trains has increased proportionately and the difficulty in supplying it in greater proportion. So it may be said that *the ability to run long trains depends almost entirely on the devices which permit the supply of air to reach the brakes on the rear end.* The difficulty always comes in releasing and recharging the brake system, for it is ever a simple matter to make the reduction necessary to apply the brakes. In other words, it is easy to allow pressure to escape, but always difficult to build it up.

In answer to the suggestion that a larger brake pipe be introduced, it can be said that, while a larger brake pipe would facilitate the transmission of air and utilize to good advantage increased compressor and main reservoir capacity on the locomotive, it would be impossible to increase the size of the brake pipe materially without disorganizing the whole air brake service, much as the introduction of the six-foot gauge would disrupt our transportation service in general. There could be no satisfactory interchange of equipment during the transition period, and the advantages of the enlarged brake pipe would not appear until practically every car

in the train was so equipped. To obtain adequate main reservoir capacity for the present side of brake pipe requires the utilization of every available space on the modern locomotive. To increase this capacity in order to realize the advantage of a larger brake pipe would be to present serious difficulties in the way of locomotive design. It is relevant to reconsider the 50 per cent. reduction in air consumption effected by the empty and load freight brake in this question of brake pipe capacity.

Modern passenger brake equipment is so designed that the pressure restored to the brake pipe serves to release the brakes only until the last stages of recharging are reached. With the old equipment, which served admirably for short trains of vehicles with small air requirements, the brake pipe recharged each brake immediately after releasing it. As train lengths and air consumption per vehicle became greater the head end equipments had more and more the tendency to bleed the brake pipe of air as fast as it was supplied, with the result that the head end was released and almost recharged before the rear end started to release. Modern brake equipments employ a supplementary storage reservoir, which is used for recharging the auxiliary during the release of the brake and for obtaining high cylinder pressure in emergency applications.

With the modern freight brake equipment (both single capacity and empty and load) the high pressure in the head end of the brake pipe, when releasing the brakes, causes the release of the head brakes to be retarded so that the rear brakes, starting later to release though they do, complete their release in practically the same time. This prevents the head cars from fully releasing ahead of and running away from the rear cars when a release of the brakes is made before the train is brought to a standstill. A retarded recharge for the head brakes permits the brake pipe air to pass on back to operate the rear brakes in a manner very essential to the successful operation of long freight trains. The importance of the ability to release and recharge the brake system promptly can only be appreciated by those who have had to contend with delay reports occasioned by control equipment used on trains of length and size beyond its capacity.

Where seconds are golden in the operation of trains, as on the New York subway system, the prompt release of a full application of the brakes on an entire train in five seconds with the new electro-pneumatic equipment, as compared with the 10 and even 17

seconds with preceding equipment, will prove to be a boon to the operating officials of that greatest railway system on earth. As retardation does not cease, or full acceleration take place, until all the air is exhausted from the brake cylinder, this saving of from 5 to 12 seconds in time, and even more when retardation is taking place, means much to snappy movement of trains. And it is well to mention that graduated release flexibility has not been impaired in this shortened time for a complete release.

TRAIN CONTROL FORMULÆ.

Computations with regard to train control have been made at various points in this paper, and a summary of all the formulæ is given in Fig. 15.

You will note that speed does not appear in the gradient formulæ. This is because no more retarding force is needed to hold a train down a grade at a speed of 40 miles per hour than at 10 miles per hour. But it is harder to get this retarding force at 40 miles per hour than it is at 10 miles per hour, because brake shoe friction is much less at the higher speed, due to the higher velocity of the wheel surfaces and the greater brake shoe heating. Therefore, the allowance for speed must appear in the value of coefficient of brake shoe friction used.

The average brake cylinder pressure needed to provide the necessary retarding force is the average between all minimum pressures occurring while the brakes are released (retainer pressures, if retainers are used) and all maximum pressures occurring while brakes are applied.

DRAFT GEAR CAPACITY.

It seems hardly necessary to dwell on the need for draft gears of improved shock-absorbing capacity when heavier cars, longer trains, locomotives of increased tractive effort, and larger velocity differences between cars in a train all point to shocks of ever-increasing intensity. It seems to be a very short-sighted policy to buy draft gears by the pound without regard for their operative characteristics and capacity—much more so, in fact, than the buying of fuel with no consideration for its calorific value.

When all trains are operated with multiple-unit control and the electro-pneumatic brake, the need that such careful attention be given to the draft gear problem will have passed away. Until then, however, it is deserving of careful consideration.

SUMMARY OF FACTORS GOVERNING TRAIN LENGTH.

We have seen that locomotive capacity, length of sidings, station platform lengths (for electric traction service), train con-

FIG. 15.

TRAIN STOPS AND CONTROL ON GRADES.

FORMULAE.

$$S = 1.467\,Vt + \frac{WV^2}{30\left(\frac{p}{C}PW_E ef - GW\right)}. \quad (1)$$

$$= 1.467\,Vt + \frac{V^2}{30\,(Pef - G)}. \quad (2)$$

when $p = C$, & $W = W_E$.

$$= \frac{V^2}{30\,Pef}. \quad (3)$$

when $G = 0$ (level track) & "t" is neglected.

$$G = \frac{pPW_E ef + rTC}{CW}. \quad (4)$$

$$p = \frac{(GW - rT)C}{PW_E ef} \quad (5)$$

$$R = \frac{pPW_E ef}{CW} - G. \quad (6)$$

LEGEND:

R = retardation factor, percent

S = stop distance, feet

V = initial velocity, m.p.h.

G = gradient; + downhill. − uphill.

P = braking ratio, based on

C = basic cylinder pressure for C. Lbs. per sq. in.

p = average cylinder press. (for grade computation)
= actual cylinder press. (for stop computation)

W_E = empty weight of car, basis for P and C.

W = actual weight, lbs.

T = actual weight, tons.

r = internal resistance of car, lbs. per ton.

e = efficiency of brake gear, averaging 85%.

f = coefficient of brake shoe friction, averaging from 10% to 20%.

t = average time, sec., train may be considered running free before the brakes get into action.

$P_L W_L$ may be substituted for PW_E when E&L brake is used.
P_L, W_L = loaded car braking ratio and weight.

trol, and draft gear capacity determine and limit the number of cars that can be satisfactorily operated in one train.

The relation of train control to train length has been enlarged upon, and investigation reveals that the air brake art has kept abreast of—in fact, always in advance of—developments in all

the many other phases of railroad activity. It is well that it has been so, for the other developments would have been impossible of full realization otherwise. A concrete example is seen in the case where the empty and load freight brake is responsible for the postponement for 25 years of double-tracking a single-track line. The importance of reduced time of serial brake action has been made clear, it is hoped, and the part played in this by the development from the first type of automatic brake to those types employing the quick-service feature, and, finally, to the perfected electro-pneumatic brake, which has reduced the time element, and therefore the shock, to zero for trains of any length and for any rate of retardation up to the limit set by the adhesion between the wheel and rail, and which is a time-saver of the first order in the way of getting the brakes on and in getting them off. Increasing weights of vehicles and increasing velocity differences between these vehicles in the ever-lengthening trains of to-day make it imperative that modern types of brake apparatus be utilized to realize more fully the opportunities at hand for increasing the efficiency of railroad operation.

The importance of uniform release and uniform recharge features of brake apparatus and the 50 per cent. saving in air consumption provided by the empty and load brake has been dwelt upon in the matter of the capacity of the brake pipe, now at its maximum, for supplying air to all the vehicles in the train.

The extreme necessity has been emphasized of employing a foundation brake rigging which will permit the full realization of locomotive performance in capacity and economy, of the advantages of all the features embodied in modern air brake apparatus, and of smooth handling of long trains with a minimum of expense and delay.

In short, the best brake is the one which, in setting up the maximum retardation, creates the least velocity differences between vehicles in a train, and which has the greatest flexibility in providing *any* degree of retardation from the very minimum to the maximum.

TIME OF STATION STOPS.

Where traffic demands are continually treading on the heels of the supply, any saving in the time a train is held at a station to receive and discharge passengers will materially increase the train-mile performance of that train. Therefore, the car door

arrangement and capacity for ingress and egress of passengers on each car should be such as to permit the " flow " of passengers along " stream lines " of the greatest number and least interference one with the other.

The same is true of the station arrangement for dividing up this flow and directing it into the proper channels.

The local conditions as to the number of passengers to load and unload will, of course, make the time of station stop a variable factor between one point and another.

Where it is necessary to change the make-up of trains which are to continue in regular service, as in interurban and rapid transit operation, any device like the automatic car, air, and electric coupler, which will make or break all air and electric connections simultaneously with the coupling or uncoupling of cars, is a time-saver of the first order.

DELAYS TO TRAINS.

Obviously, if the yard capacity at division points is such as to require dispatchers to delay trains on the road pending the ability to receive them at the terminal, improvements made for improving road conditions can profit but little; and similarly with making up trains and starting them out.

The relation of defective or inadequate equipment in causing delays to trains needs but brief mention. The use of archaic equipment in the way of foundation brake rigging and air-controlling devices can but promote trouble in operating trains of modern weights and lengths. Delays due to stuck brakes, hot boxes, slid flat wheels (where passengers have to be transferred from one sleeper to another in the dead of night), hard pulling trains, and break-in-twos are some of the troubles which can readily be avoided by paying due attention to the underlying principles existing in the relation of train control to train operation.

ACCELERATION.

Traffic capacity will depend on the time needed to accelerate a train up to a maximum speed, and this, in turn, will depend upon the motive power, locomotives, steam and electric, and motor equipments for electric railways.

The accelerative performance of motor equipments depends on a host of things such as design, clearances, etc. Among these are

line-voltage regulation and the assistance here rendered by the current returned to the line due to regenerative braking in the control of trains on grades and in making stops. Selective relays operated by differences in the condition of car loading provide uniform acceleration, irrespective of whether the car be empty, partially or fully loaded.

The comparative number of motors and trailers in the train will, of course, determine the rate of acceleration possible. The new cars for the New York Municipal are all motors. The operation of all motor trains is the reasonable way to provide for maximum traffic, which goes without saying.

Much has been claimed, and deservedly, for the superheater, the brick arch, the feed-water heater, and the mechanical stoker in improving locomotive performance in the way of capacity and economy. The modern locomotive is really a very efficient machine, having a water rate as low as 14.5 pounds, compared with 8.5 for large steam turbine units. Except at very low speeds, locomotive capacity is entirely dependent upon the ability of the boiler to supply steam, and all of these improvements pertain directly to the boiler. In many cases the advantage of these improvements in the way of increased tonnage has been cut off by the inability to start the trains from rest. It is readily seen, therefore, that acceleration is governed by the brake shoe clearance maintained, for the harnessing of improved boiler performance cannot be realized if the train cannot be started under way. A foundation brake rigging which will maintain proper brake shoe clearances and thereby eliminate increased train resistances due to dragging brake shoes is vitally pertinent to each and every class of railway service.

Conditions of grade will obviously affect acceleration of trains. Ascending grades for the approach to stations and descending grades for the departure therefrom are of great importance and efficiency in improving rates of acceleration and retardation. These have been employed on the New York subway at a number of points.

MAXIMUM SPEED.

Acceleration is the first factor to dictate the maximum speed physically possible. The station spacing enters in the way of providing or failing to provide, first, the time necessary to get up to maximum speed, and, second, the period during which this speed

can be maintained before it is necessary to stop, which influences the average speed over a division.

The retardation phase, however, determines what is the safe maximum speed. New brake devices, which give for emergency high retardation rates over those developed for service operation of the brakes, and electro-pneumatic control, which makes these high rates possible without tearing up the train, have boosted the safe speed to a point which for other reasons railway managers do not care to approach.

In grade service the maximum speed will depend upon the reserve braking force, the heating of brake shoes and car wheels, and local conditions, such as curvature and changes in grade. With the single capacity brake it is necessary to crawl down mountain grades, because the margin, or breaking reserve, between control and a runaway train is so very small. At low speeds the coefficient of brake shoe friction is high, making a more efficient brake, and the time provided for recharging the brake system, before the increase in speed has taken the brake shoe friction to a greatly reduced value, is prolonged. The empty and load brake, with air consumption reduced one-half and brake effectiveness increased two and a half, or more, times, permits materially increased speeds down mountain grades. The braking reserve, increased anywhere from 500 to 1000 per cent. more, enables a stop to be made in a very short distance at any time during the descent of the grade, where the corresponding stop with the single capacity brake is measured in thousands, instead of hundreds, of feet.

Curves also have an influence on the maximum speed which can be made. Slow-downs for curves consume both time and energy.

RETARDATION.

The relation of retardation to the traffic volume handled by the train unit has been discussed at great length elsewhere in this paper. Retardation depends, of course, on the maximum speed, because the energy to be removed from a moving train in bringing it to rest varies as the square of the speed; that is, as the speed is doubled the stop distances will be multiplied four times, other things remaining constant.

The energy of a moving car varies directly with the mass or weight. Therefore, other things remaining equal, the stop dis-

tance will lengthen as the weight is increased. This explains why the hand brake is so inadequate for modern car weights. The brakeman of to-day is no stronger than the one of yesterday, but car weights have doubled, tripled, and even quadrupled. If more effectiveness is sought by increasing the leverage, or by applying hand brakes separately to each truck, the time element for getting the brake into action is greatly increased, which offsets the gain in braking effort.

Every second's delay in getting the brakes into action means, at a speed of 60 miles per hour, the addition of 88 feet to the stop distance. To handle the great volumes of air required for modern equipment with the least possible loss of time requires the use of devices of the most careful and scientific design.

The questions of brake shoe duty; uniform braking ratio; number of cars; serial action; air brake equipment necessary for cutting down the times for getting the brakes applied and for serial action, and for maintaining a constant braking ratio, whether the car be empty or loaded; a suitably designed foundation brake gear which will avoid, among many others, that evil in the form of low effective retardation due to the attempt to "dribble" on the brakes and avoid shocks—all of these have been examined before.

RAIL CONDITION.

When the brakes are applied on a car, each wheel thrusts forward on the rail with a force equal to the brake shoe friction on that wheel. The equal and opposite thrust of the rail against each wheel is the force which, applied from a point external to the vehicle, causes retardation. Obviously, if a demand of this sort is made on the rail in excess of the static or rolling friction (generally termed "adhesion") between the wheel and the rail, this friction will fail to keep the wheel turning and the brake shoe friction will cause the wheel to slide. The wheel-rail friction, now kinetic in nature, will be very much reduced and the actual retarding force acting on the wheel correspondingly reduced. From this it is evident that *the braking problem must begin and end with the rail.* If the condition of the rail surface is bad—which is another way of saying that the coefficient of friction is low—the amount of brake shoe friction that can be used without causing wheel sliding is very much reduced, and likewise the retardation possible.

As before mentioned, the retardation in percentage (or, what

is the same thing, the actual retarding force in relation to the weight of the vehicle) is expressed according to standard nomenclature.

$$R = \frac{p}{C} P\,ef$$

Where the actual cylinder pressure (p) equals the pressure (C) used as a basis for the braking ratio (P), this expression is simplified, thus:

$$R = P\,ef$$

Now if A be the designation for the adhesion, or coefficient of rolling friction between wheel and rail, the critical point for wheel sliding will be when the retarding force equals the adhesion; that is,

$$P\,ef = A$$

The actual value of the adhesion, A, will vary from 12 to 30 per cent., depending upon the weather conditions of temperature and relative humidity. With sand on the rail it may run even higher than 30 per cent. Taking an efficiency factor of 8 per cent. and an adhesion value of 25 per cent. (which is representative of the usual condition of rail surfaces), the braking ratio (P) necessary to slide wheels is

$$P = \frac{A}{ef} = \frac{.25}{.08} = 312.5 \text{ per cent.}$$

On the other hand, if the adhesion drops to 12 per cent., due to uncontrollable weather conditions, the braking ratio necessary to slide wheels is only

$$P = \frac{.12}{.08} = 150 \text{ per cent.}$$

If in the latter case the efficiency factor be 24 per cent., the braking ratio need be but 50 per cent. to cause wheel sliding. Thus it is appreciated that the dependence of the whole problem of braking comes not, as popularly believed, upon the question of braking ratio alone, but upon the values of wheel-rail and shoe-wheel friction as well, for here we have illustrations of wheel sliding with braking ratios varying from 50 to 300 per cent.

REGENERATIVE BRAKING.

The difference between a train in motion and a train at rest is one of kinetic energy content. In order to bring a moving train

to rest it is necessary to remove this energy, and until recently the only available means was to cause it to flow from the train through the brake shoes in the form of heat energy and to be dissipated and lost in the surrounding atmosphere.

As illustrated in Fig. 2 (p. 427), the energy content of a modern train, due to greatly increased mass and velocity, is such that, could it be properly directed and harnessed, it would carry the full load of an 8000-kilowatt power plant for one minute's time. Any means, then, for saving this energy for use in accelerating trains is an economy of vital importance. Electric operation of trains provides an opportunity for effecting this saving in that suitable motor control apparatus can direct the driving effect of the moving train to operate the motors as generators and return thereby the kinetic energy of the train to the line in the shape of electrical energy. This is regenerative braking. In addition to the energy saving, wear and tear on car wheels and brake shoes is avoided.

However, contrary to the expectations of the uninitiated, the need for modern air brake installations is just as pressing with regenerative braking as without it, for otherwise, in event of any failure in the line or in the motor equipment, the train would be altogether uncontrolled. Moreover, where regeneration is employed with the electric locomotive, the responsibility for control is vested in one or two units, and a failure of one or both means a failure of half or all the power to control. On the other hand, with an air brake equipment on every car in the train, a failure of one, two, six, or ten units (depending on the total number in the train) will be of relative insignificance.

Thus it is apparent that to realize the best economies in the control of freight trains down mountain grades with the regenerative brake it will be necessary to employ the empty and load brake in order to provide the braking reserve indispensable to speed and safety. Otherwise, if the single capacity brake is employed and the safe speed for this type of brake is exceeded at any time during regeneration, a failure of the regenerative brake means a runaway train.

The subject of regenerative braking is worthy of a paper in itself, but the foregoing sketch will suffice for the purposes of this general treatise.

SYSTEM OF TRAINS.

HEADWAY OR SPACING OF TRAINS.

The fundamental consideration for the headway or spacing of trains is the element of *safety*. Safety of operation in turn depends upon the possible retardation or ability to stop; the maximum speed; and the installation and characteristics of signal apparatus. These factors are arranged in order of relative importance, though, of course, each is closely bound up in, and not to be dissociated from, the others.

The minimum headway for the movement of trains may be determined in two different ways. One method is to base the proper time interval between trains on a system of trains *running at maximum speed*. The other is to base this time spacing on the *closing-up of trains at stations*. The method of these two which gives the larger minimum headway must be the one to use for the conditions in question, for, obviously, of two critical values the safer, which is the larger, must always be chosen.

In the subsequent analysis certain assumptions are to be understood, namely: straight and level track with no irregular local conditions and carrying traffic in one direction only; a block section equal in length to *twice* the emergency stop distance from the maximum speed; stop distances proportional to the square of the maximum speed; duration of retardation directly proportional to the maximum speed.

It is needless to attempt an investigation of this kind with a thousand-and-one variables. The modifications necessary to apply the results herein established to special conditions of grade, curvature, interlockings, and other local conditions will be apparent, once these results are understood. The above assumptions are sufficiently accurate in every respect to make worth while this analysis of the factors influencing headway for train movements.

No attempt will be made to deal with the laying out of a signal system for the system of trains here considered. These data can be found elsewhere, a couple of very good treatments of this proposition being found in Mr. H. G. Brown's paper, "The Signalling of a Rapid Transit Railway," read before the Institution of Electrical Engineers in April, 1914, and in Mr. M. L. Patterson's article, "Methods of Locating Automatic Signals," in the *Railway Signal Engineer* for February, 1916.

In general, trains running at speed should be spaced by a distance equal to the sum of:

1. The length of the train.
2. The length of the complete block section.
3. The distance between the distant and home signals.
4. The distance sufficient to permit the signal to clear and the engineman to identify the signal indication.

In the New York subway the overlap system of signals is used, which provides for *two* home signals and one distant signal protecting the rear of each train. In order to give each following

FIG. 16.

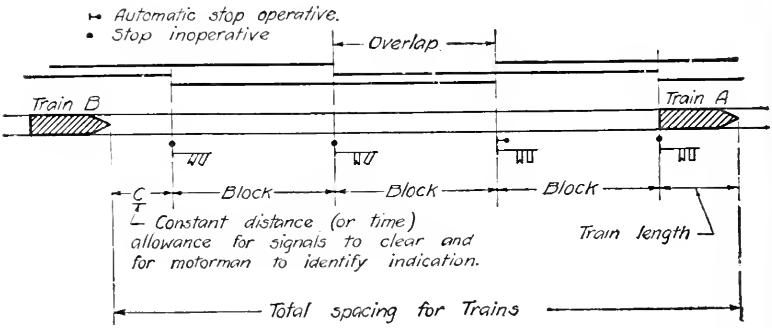


DIAGRAM OF OVERLAP SYSTEM OF BLOCK SIGNALS, ILLUSTRATING SPACING OF TRAINS.

train a clear distant signal (and this should be the normal condition), the complete block section plus the distance between the distant and the second home signal should be taken as three times the length of a block, or as six times the emergency stop distance.

The distance spacing for this system is illustrated in Fig. 16. Constant C (item 4 in the list above) may be a given *distance* or a given *time*. If taken as a constant distance, the time will vary, of course, according to the speed. The *time* spacing or headway between trains will be the time necessary to run this total distance spacing, or, expressed mathematically,

$$H_R = \frac{6S_E + NL + C_S}{1.467\ V} \tag{1}$$

where:

H_R = headway determined by running at speed (seconds);
S_E = emergency stop distance (feet) from
V = maximum speed (mph);
C_S = *space* constant (feet);
N = number of cars in train;
L = length of each car (feet).

While the kinetic energy of a train varies directly with the square of the speed, the retarding force, due to the brake shoe friction, is decreased with an increase in speed. On the other hand, the initial or reflex time required for getting the brakes into action—constant, of course, for any speed—is of decreasing importance, relative to the total time for stopping, as the speed is increased. It is found that the influences of these two factors, reflex time and brake shoe friction, are approximately counteractive, and, therefore, the stop distance will vary directly with the square of the speed; that is, the braking distance will equal some constant times the square of the speed. Whence, substituting in (1)

$$H_R = \frac{kV^2 + NL + C_S}{1.467\,V} \tag{2}$$

If the allowance C, as illustrated in Fig. 16, be taken as a *time* instead of a space constant to permit signals to clear and motorman to identify them, (2) becomes

$$H_R = \frac{kV^2 + NL}{1.467\,V} + C_t \tag{3}$$

Solving (3) for V, we have in quadratic form

$$V = .733\frac{(H_R - C_t)}{k} \pm \frac{\sqrt{2\,15(H_R - C_t)^2 - 4\,kNL}}{2k} \tag{4}$$

The curves for the relation between H_R and V as expressed by (2) are plotted in Figs. 18 and 19 and those for (3) in Fig. 21.

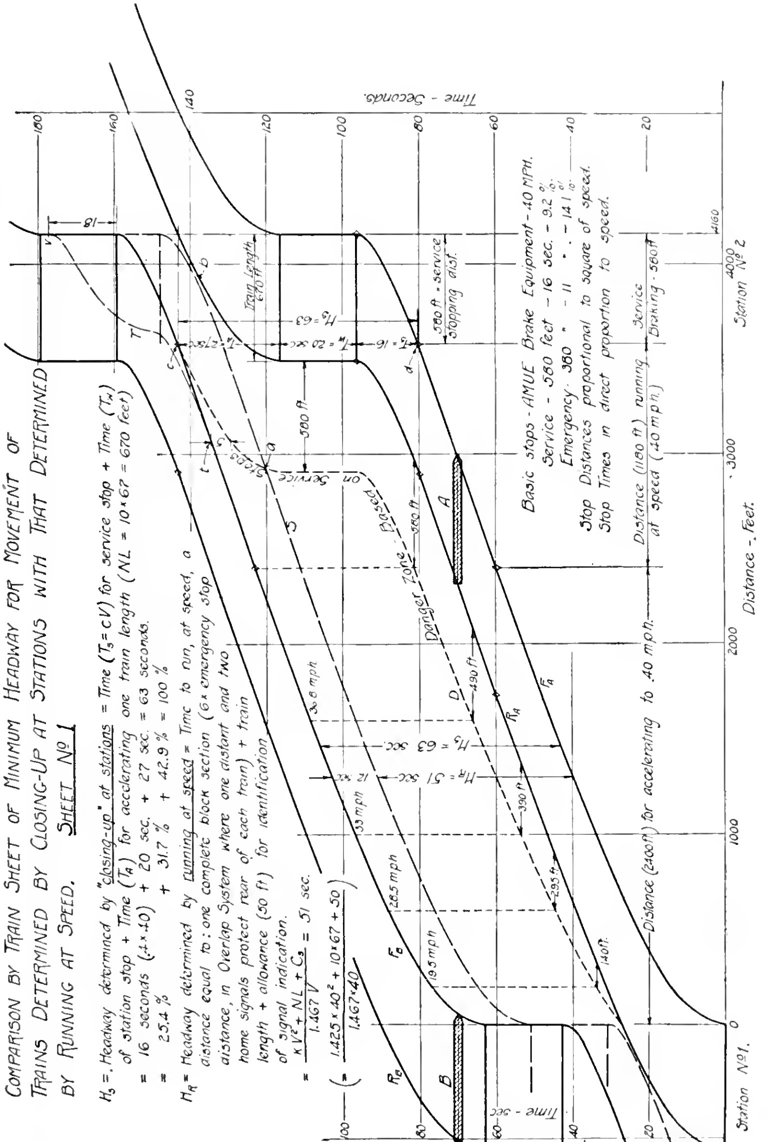
Curves for train lengths of zero, 335, and 670 feet are shown, and for each there is a critical speed for the minimum headway; that is, for each length of train there is a critical speed above or below which a headway obtains greater than that at the critical speed. A curve giving the locus of all such critical points for every length of train is indicated on both Figs. 18 and 21. The headway increases for speeds lower than these critical points because the length of train is of increasing relative importance; that

is, the length of train, with decreasing speeds, more nearly approaches the length of the block section—it being kept in mind that the latter is always a function of the speed under these considerations. The headway increases for speeds higher than the critical value because the braking distances and, therefore, the block sections are longer, increasing as the square of the speed, while the time required for covering a certain distance decreases in inverse ratio only directly as the speed.

The headway determined by closing-up at stations is illustrated in Fig. 17, and a comparison made with the headway determined by running at speed. The progress of two trains, *B* following *A*, from one station to another is traced by the lines *F* and *R*. These lines mark the progress of the front and rear ends of each train on a time-distance basis. Train *B* is shown just having left the first station at the time (70 seconds) after train *A* has advanced from this station about 3000 feet and is running at full speed. Train *A* stops at the second station, 4160 feet from the first, at about 96 seconds after leaving the first. After a station stop of 20 seconds as shown, it starts again for the third station (not shown).

Curve *D* (dotted) marks the danger zone inside which the head end of train *B* must not come if the rear end of train *A* is to be safe. This zone is based upon the service braking distances for the speeds at which train *B* is running under normal operation at the particular points in question along the right-of-way. Curve F_B is tangent to curve *D* at point *c* where braking must begin for the stop of train *B* at station two. The time interval between this critical point for train *B* and the corresponding point *d* for train *A* is the headway (H_S) determined by trains closing up at stations, and is seen to be the sum of: (1) the time to make the service stop (T_s); (2) the time the train is held at the station (T_w); and (3) the time required to accelerate one train length (T_a). This is the limiting or critical value for the headway and cannot, of course, be realized in actual practice, because, among other things, the time of station stop will change with the varying number of passengers to be handled. Suppose, under the condition shown, the time of station stop for train *A* had been lengthened five seconds. This would cause an intersection of curve *D* with F_B at *t*, requiring that train *B* start braking at this point and advance to the usual station stop at point *v*, as indicated by curve

FIG. 17.



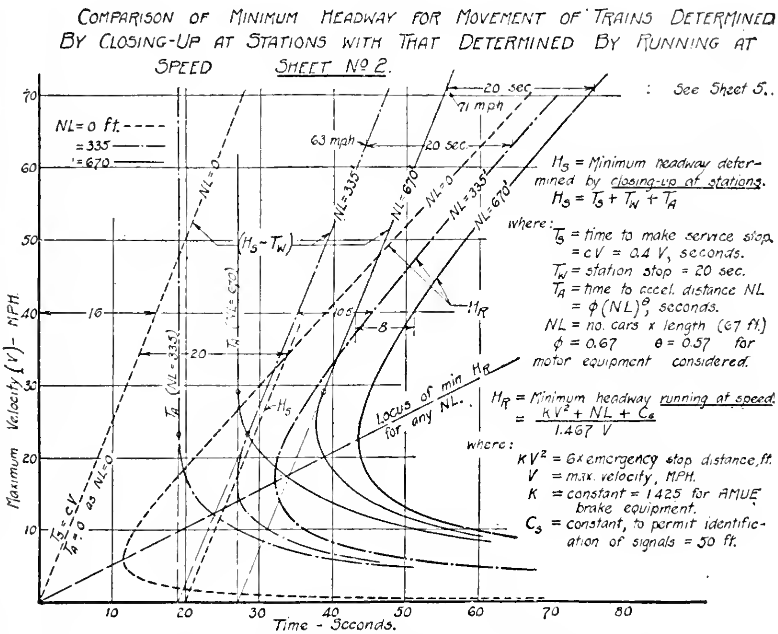
A train-sheet illustration of the relative progress of two trains, according to time and distance, from one station to another. For the conditions shown, "closing up" at stations will determine the headway or spacing of trains.

T. In this case the initial delay of five seconds has resulted in a final delay of 18 seconds. This would react correspondingly on the trains following *B*, causing an ever-accumulating delay until the whole service would be disorganized. The actual headway for service must allow a comfortable safety factor to avoid troubles of this kind. However, for the purposes of comparison, the theoretical minimum for headway will be used in every case unless otherwise noted.

Examination of the three factors that go to make up the headway based on closing-up at stations reveals that, with the assumed conditions of speed (40 miles per hour), service braking distance (580 feet) and time (16 seconds), and time (27 seconds) to accelerate one train length (670 feet), the time for service braking is only 25 per cent., the time of station stop 32 per cent., and the time to accelerate 43 per cent. of the total headway of 63 seconds. The recent improvement made in the electro-pneumatic brake in reducing by two seconds the reflex time for brake application still further diminishes the *comparatively slight interference which the modern brake offers to the proposition of operating trains without any headway at all.* In other words, the air brake art, as exemplified in rapid transit service, has come to that stage of perfection, has so far maintained its lead in advance of the other factors entering into the movement of trains, that a 10 per cent. improvement in the brake performance would now result in only 2.5 per cent. betterment in the total headway; whereas, a 10 per cent. improvement in the acceleration would mean a 4.3 per cent. reduction in headway, or almost twice the saving. Do not make the mistake of believing that the part of the brake here resembles a 10 per cent. saving in the cost of brass buttons for the conductor, which results in a net overall saving in operating expenses of one ten-thousandth of one per cent. or less. It should not be necessary to emphasize the fact that the ability to move trains at all depends upon the ability to control them. When it is considered that the brake equipment in the same subway service in 1906 required 41 seconds and 1450 feet, with no measure of the same application flexibility and no release flexibility whatever, to make the stop now requiring but 14 seconds and 500 feet, the significance may be better grasped of the above comparison as to realization of opportunity and fulfilment of economic trust in the development progress of the air brake.

Curve *S*, Fig. 17, represents the time-distance path of the front end of train *B* following *A* on a headway (H_R) of 51 seconds, determined by running at the maximum speed of 40 miles per hour. This is 12 seconds less than the headway (H_S) determined by closing-up at stations. Therefore the latter must govern; for note that curve *S* enters the danger zone at *a*, and if train *B* were permitted to continue as indicated by *S*, it would come within 40 feet of train *A* at *b*. Were anything to detain train *A*

FIG. 18.



A detailed analysis and comparison of the two methods of figuring headway; one based upon "closing up" at stations, and the other upon "running at speed."

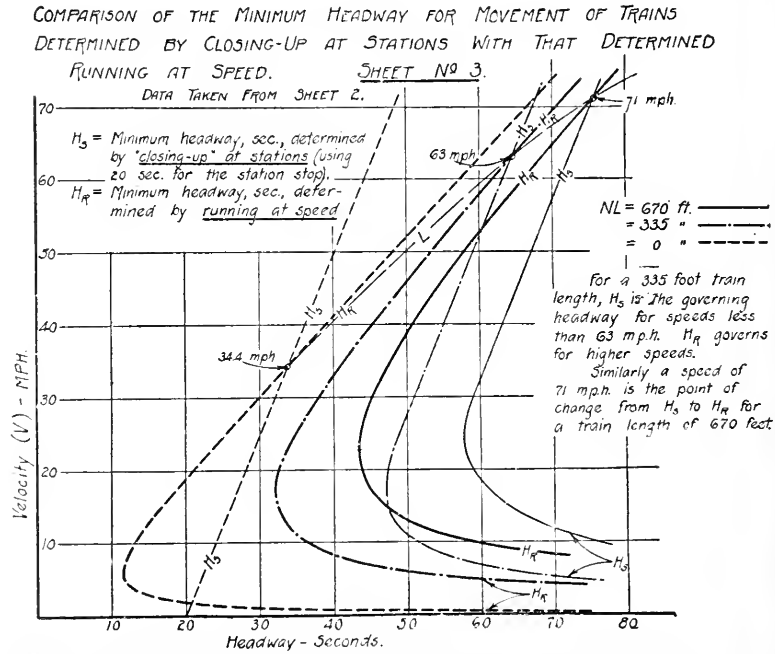
by one second or more, either at the station or after starting therefrom, a collision would be the result. Were braking to commence on train *B* at point *a*, due to a proper signal observance of the danger zone, the initial delay of 12 seconds would be multiplied into a final delay several times as great.

A more detailed analysis of the relations between the headways H_S and H_R may be found in Figs. 18, 19, and 20. Fig. 18 gives a complete development of the various factors which go to make up the two species of headway. The time for accelerating

different train lengths is given by the formula in the legend, and also graphically on Fig. 26. Some of the bases in the way of braking distances and times appear on Fig. 17.

Fig. 19 is a summary of results taken from Fig. 18. The heavy lines represent the "running" headway (H_R), and the light lines the "station" headway (H_S). The dotted lines are for zero train length; the dash and dot lines for a train length of 335 feet; and the full lines for a train 670 feet long. Curves for

FIG. 19.



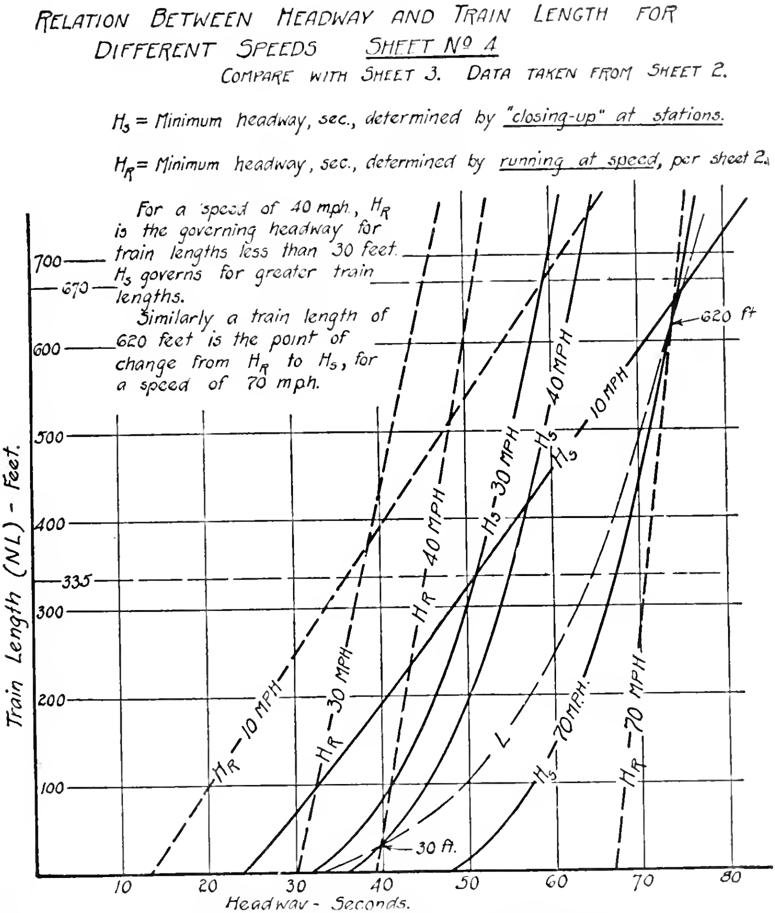
A summary of the results of Fig. 18. For speeds below a critical value (which is higher as the train length is increased) the headway based upon "closing-up" at stations will be the larger and therefore the determining value for the spacing of trains.

zero train length are given to show what the limiting conditions are when a train is considered as a point only. Curve L gives all points where, for any train length, H_R equals H_S; that is, it relates the speeds and these equal headways for any train length. Thus for a 335-foot train length H_S is greater than H_R, and will, therefore, be the governing headway for all speeds under 63 miles per hour. At that speed the two headway curves cross and mutually indicate a headway of about 64 seconds. Above this

speed H_R is the greater and must, therefore, be the governing headway.

Fig. 20 gives the relation between train length and headway for various speeds. The dotted lines show the variation

FIG. 20.



The running headway will determine the spacing of trains for train lengths less than a certain critical value (which is greater as the speed is higher).

of running headway with train length, and, similarly, the full lines for station headway. As the speed is higher the dotted lines become more and more erect, showing that the train length becomes of decreasing relative importance for the higher speeds; that is, a

change in train length affects the running headway less as the speed becomes higher. Not so with the station headway, however, for a change in train length naturally affects the time to accelerate that distance by a constant amount, unless the speed be lower than that ordinarily attained by the train at the time it has accelerated a distance equal to the train length. Under such a condition, after the train has attained it, this speed must be continued for the balance of the train length, which, of course, lengthens out the time for the train to move from rest a distance equal to its own length. This explains why as the speed decreases below a certain critical point the curves for H_S in Fig. 19 and for $(H_S - T_W)$ in Fig. 18 turn to the right, indicating increasing headways for decreasing speeds. For a train of zero length the time to accelerate that distance is, of course, also zero, and, therefore, the H_S curve for this length of train does not swerve to the right, but continues to decrease with decreasing speeds.

Curve *L*, Fig. 20, is the locus of all points where H_S and H_R are equal; that is, H_S and H_R are both equal to 74 seconds for a train length of 620 feet and a speed of 70 miles per hour. Curve *L* joins all such points.

The two curves *L*, Figs. 19 and 20, taken in conjunction with the other curves, describe in a very complete manner the relative jurisdiction of the two headways, "running" and "station," as to the point where one takes precedence over the other. They reveal that improvements in the way of higher rates of acceleration, reduced time of station stops, and higher maximum speeds will cause the running headway to be the determining factor over a wider range of train operation in the way of increased train lengths. Improvements in brake effectiveness (higher retardation rates), though they may affect both service and emergency braking in the same proportion, will nevertheless reduce the "running" headway to a much greater extent than they will the "station" headway, because of the former's larger dependence upon the braking factor. These improvements in braking will, therefore, have an effect opposite to the above by making the station headway the determining factor over a wider range of train operation in the way of increased speeds and longer trains.

An isolated example appeared in connection with Fig. 17, where an initial delay of 5 seconds to a train was multiplied into a final delay of 18 seconds. Fig. 22 has been prepared to portray

more generally the relation of various rates of uniform retardation and acceleration to multiplication of initial delays in train movement into final or resultant delay. By "initial" delay is here meant the difference between the time a train passes a certain spot

FIG. 21.

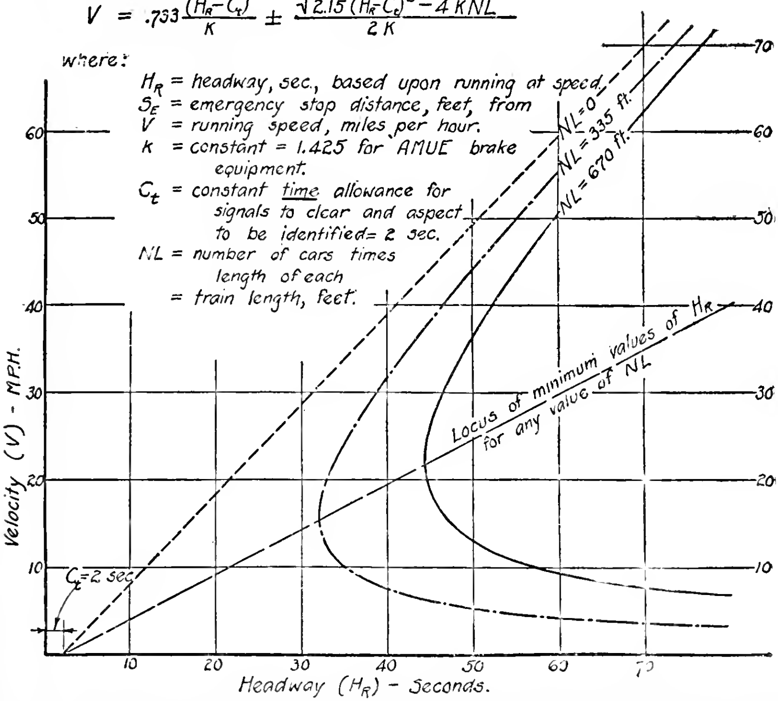
RELATION BETWEEN SPEED AND THE MINIMUM HEADWAY BASED UPON RUNNING AT SPEED. SHEET No. 5.

Compare with Sheet 2 and note factor C in the expression for H_R. There C appears as a space constant; here as a time constant.

$$H_R = \frac{6\,S_E + NL}{1.467\,V} + C_t = \frac{KV^2 + NL}{1.467\,V} + C_t$$

or

$$V = .733\,\frac{(H_R - C_t)}{K} \pm \frac{\sqrt{2.15\,(H_R - C_t)^2 - 4\,KNL}}{2\,K}$$



The allowance for signals to clear and for enginemen to identify their indication may be taken in terms of distance or of time. This shows the result where the allowance is made in *time*. Fig. 18 makes the allowance in *distance*. This applies only to "running" headway, of course.

at the lowest speed to which it has had to slow down and the time it would have passed this spot had it continued at maximum speed. Thus, if a complete stop is made from 40 miles per hour in 18 seconds (a retardation rate of about 10 per cent.), the initial time

lost is not 18 seconds, but only 9, for it takes the train 9 seconds to traverse the stop distance at full speed. If it takes 40 seconds to return from rest to full speed at a uniform acceleration of one mile per hour per second, the delay this occasions is not 40 seconds, but 20, for it takes 20 seconds to traverse the acceleration distance at full speed. The total delay to this train, then, for an initial delay of 9 seconds (which just brings it to a stop) is $20+9=29$ seconds; that is, the initial delay of 9 seconds has been multiplied a little over three times. The time the train remains at rest is added, of course, to the initial and final delay alike.

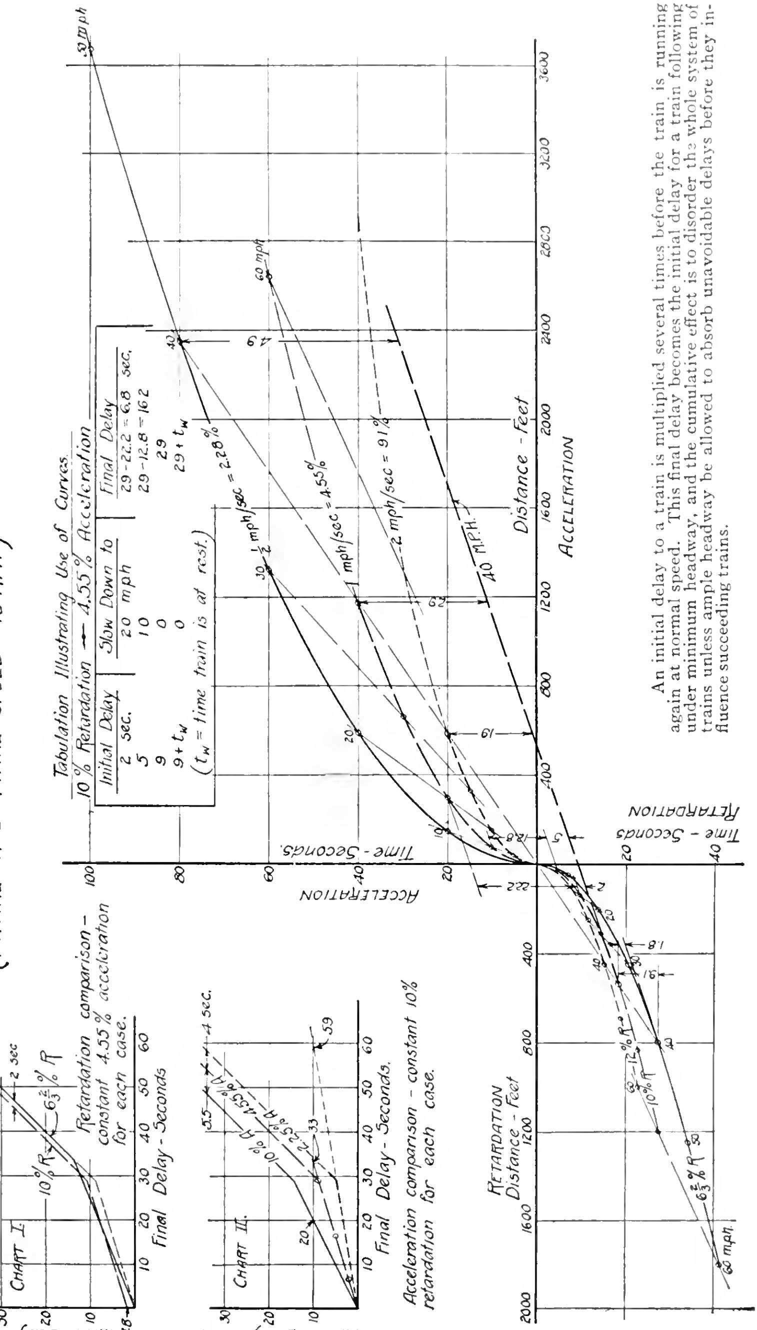
Chart I in Fig. 22 compares the effect of various retardation rates on this delay multiplication when the acceleration is constant. With the higher retardation rate braking can commence later, other things remaining equal, and effect the same result obtained by the lower rate of retardation. In the comparison made between a 6⅔ per cent. and a 10 per cent. retardation, the latter was, therefore, given an advantage of 1.8 seconds, determined by construction as shown in the main figure; that is, the 6⅔ per cent. train had to retard 1.8 seconds before it was necessary for the 10 per cent. train to start retardation. However, the curve for the latter (Chart I) crosses the former twice, first overtaking it (the 6⅔ per cent. curve) because of greater effectiveness and then receding from it beyond the jog in the curve because of coming to a full stop in reduced time. The two curves finally parallel one another, with a final delay difference of two seconds in favor of the better brake. The dotted curve makes the comparison without allowing the 1.8-second handicap.

A tabulation is given illustrating the method of using the data taken from the dimensioned main curve to relate the initial to the final delay. The example given is the one involving constant rates of retardation and acceleration of 10 per cent. and 4.55 per cent., respectively. The other rates are handled in similar fashion.

Chart II shows the relation between various rates of acceleration in this matter of multiplying initial into final delay, with the rate of retardation constant at 10 per cent., in order to have but one variable in the problem at a time. Up to the point of coming to a complete stop (indicated by the jog or turn in each curve) the 10 per cent. acceleration rate gives a multiplication factor of two, the 4.55 per cent. (one mile per hour per second) a factor of 3.3, and the 2.25 per cent. rate multiplies the initial delay by 5.9 into

FIG. 22.

RELATION OF VARIOUS RATES OF RETARDATION AND ACCELERATION TO MULTIPLICATION OF INITIAL DELAY IN TRAIN MOVEMENT INTO FINAL OR RESULTANT DELAY.
(INITIAL AND FINAL SPEED 40 MPH)



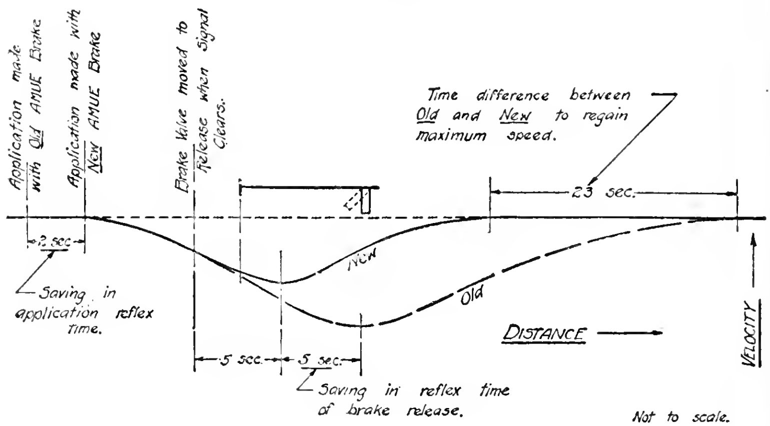
An initial delay to a train is multiplied several times before the train is running again at normal speed. This final delay becomes the initial delay for a train following under minimum headway, and the cumulative effect is to disorder the whole system of trains unless ample headway be allowed to absorb unavoidable delays before they influence succeeding trains.

the final delay. As is to be expected, the better the acceleration the less the final delay.

Any speeds other than 40 miles per hour may be investigated in like manner for delay multiplication. The lower the speed the less the multiplication will be, other things remaining the same, for, obviously, the less retarding and accelerating there will be to do. The reverse is true of higher speeds.

The value of the new electro-pneumatic brake may now be well appreciated in its saving of 2 seconds in reflex time of brake application (time from brake valve handle movement to rise in

FIG. 23.



GRAPHICAL ILLUSTRATION OF WHAT THE SAVING IN REFLEX TIME OF BRAKE APPLICATION AND RELEASE MEANS TO THE OPERATION OF TRAINS

brake cylinder pressure) and its release of the brakes in 5 as compared with from 10 up to 17 seconds. This time saving amounts to from 5 to 12 seconds for release and, adding the 2 seconds application saving, the total saving is from 7 to 14 seconds. In slowing down for a signal it is as necessary to get the brake off as it is to get it on, under operating conditions where the second is the unit of time schedule. And the delayed necessity for applying the brakes may mean in many cases no necessity for applying at all, because the signal may go to "clear" within the 2 seconds which are saved in reflex time. Therefore, the total saving in *initial delay of*

from 7 to 14 seconds means a final total saving of anywhere from *14 to 40 seconds resultant delay*, depending on the multiplication factor applying in the particular case. If the minimum saving of 7 seconds be taken with the acceleration rate of one mile per hour per second, which is higher than actually realized, and with a 10 per cent. retardation rate, according to Chart II, Fig. 22, the saving in final delay is about 23 seconds. A 23-second initial delay for the following train is multiplied into 43 seconds final delay, and this, as initial delay for the third train, becomes 63 seconds initial delay for the fourth train, and so on. The significance of the 7-second saving becomes apparent in its cumulative effect on succeeding trains. This presupposes, of course, that trains are following each other under minimum headway, and the necessity for allowing a delay, or safety, factor in the headway actually used is again emphasized.

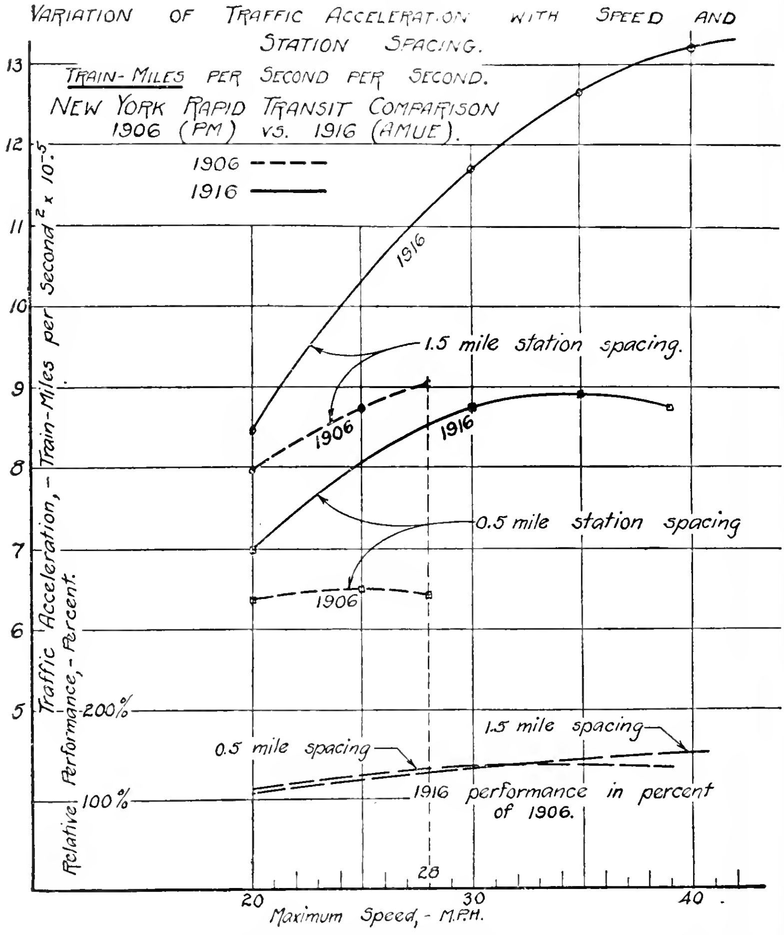
Fig. 23 is a graphical illustration of the foregoing points. It is not drawn to scale, but supplements Fig. 22 in picturing the time lost before a train which has slowed down can get back to speed, and the value of a brake which eliminates reflex time to the maximum degree.

To compare the traffic capacity theoretically possible in 1906 on rapid transit lines in New York City with that now possible Figs. 24 and 25 were prepared. Fig. 25 shows a gain of 350 per cent. in traffic performance. This is a comparison of 300,000 with 1,350,000 people handled daily. Though the absolute values of these curves are not of any actual state of affairs, because account is not taken of local conditions and practical operating allowances, they are interesting for the theoretical maximum limit which they point out. Nevertheless, for comparative purposes they are of as much meaning as though they were, in the first place, practical instead of theoretical values.

The traffic capacity unit of these curves is the *train-mile* (*or passenger-mile*) *per second per second.* This is an acceleration unit representing the *increase in traffic handling facilities which can be made in unit time* to care for the peak loads of rush hours. This acceleration unit is found by dividing the average or schedule speed over a given distance (including station stops) by the headway. If the average speed, V_s, be in miles per second and the headway, H_s, be in seconds per train, the quotient will be "train-miles per second per second." The corresponding unit, "passen-

ger-miles per second per second," is found by multiplying the train-mile factor by the train capacity in passengers. This factor stands in the same relation to train-miles and time that accelera-

FIG. 24.



The average or schedule speed of trains in miles per second over a district divided by the seconds headway intervening gives a *traffic acceleration unit*—train miles per second per second. This is a measure of the ability to get trains into operation quickly to care for peak traffic loads. Modern brake equipment has rendered possible an increase of 50 per cent. over 1906 performance in the number of longer trains it is possible to introduce into operation in a certain period of time.

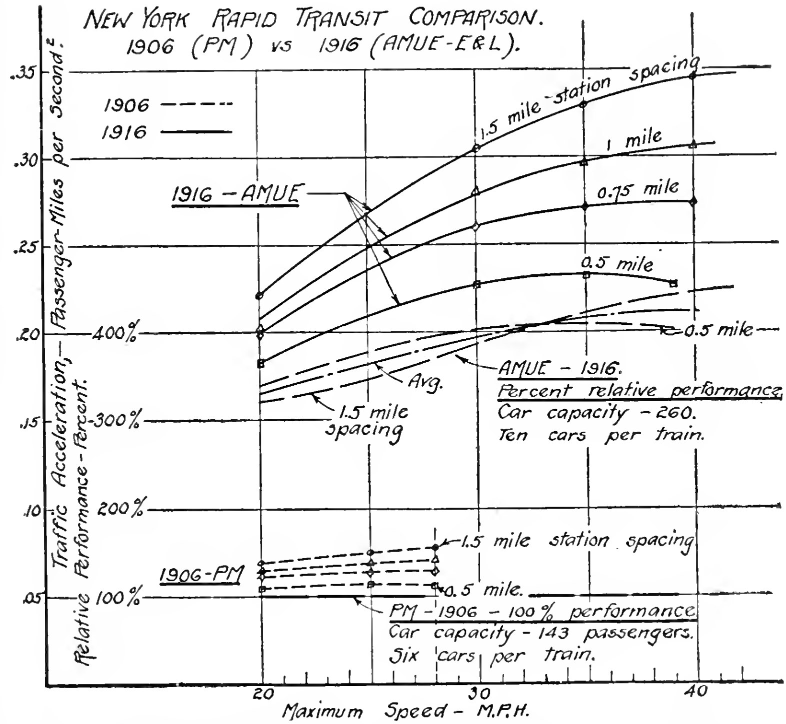
tion, as generally known, stands to space and time. Thus, where velocity equals acceleration times the time, the number of train-miles per second operating at any instant equals the traffic accelera-

tion factor multiplied by the time during which it has been in play. Of course, after a railway system has become completely filled with trains a maximum velocity, or number of train-miles per second, has been attained and more trains cannot be introduced; also, as

FIG. 25.

VARIATION OF TRAFFIC ACCELERATION WITH SPEED AND STATION SPACING.

PASSENGER-MILES PER SECOND PER SECOND.



The results of Fig. 24 are here shown in terms of *passenger-miles* per second per second. Due to the use of modern train control equipment, it is possible to introduce 350 per cent. more traffic-handling facilities in a certain period of time than was possible in 1906.

the number of points for introducing trains is increased the portion of the entire railway system per point is decreased and, therefore, the time for filling to maximum capacity is also decreased. In this discussion it is to be understood that the term "railway

system " applies to that portion supplied from *one point.* Many interesting analogies will come to mind in the consideration of this newly evolved acceleration factor, of which extended discussion will not be here made. Mathematically these analogies may be summed up:

SPACE

1. $v = v_o + at$
2. $s = v_o t + \frac{1}{2} at^2$
3. $v = v_o + \sqrt{2as}$

where:

v = velocity, feet per second.

a = acceleration, feet per second^2.

t = time, seconds.

s = space, feet.

v_o = initial velocity at beginning of time, t.

TRAFFIC

1. $V = V_o + At$
2. $M = V_o t + \frac{1}{2}At^2$
3. $V = V_o + \sqrt{2AM}$

where:

V = train-miles (or passenger-miles) per second.

A = train-miles per second$^2 = \frac{V_s}{H_s}$

V_s = average speed over district, miles per second.

H_s = headway between trains seconds.

t = time, seconds.

M = train-miles (or passenger-miles).

V_o = M per second at beginning of time, t.

In 1906 PM brake equipment was in use, which set an operating limit to train length of six cars. These cars were 51 feet in length. To-day the electro-pneumatic, empty and load, brake (designated AMUE – E&L) is the last word in control equipment, which sets no limit as to train length, but station platforms can accommodate trains not longer than 10 67-foot cars. The car capacity then was 143 passengers, as compared with 260 now—an improvement due in no small measure to the empty and load feature for uniform rates of retardation and acceleration irrespective of the condition of car loading.

For different conditions of uniform station spacing the schedule or average speed (V_s) in miles per second will be determined by the distance from one station to the next in miles, divided by the sum, in seconds, of the times of: acceleration, running at maximum speed, deceleration, and station stop. Figs. 26 and 27 give, for the old and new conditions, the acceleration characteristics used as bases in the comparative traffic capacity curves of Figs. 24 and 25.

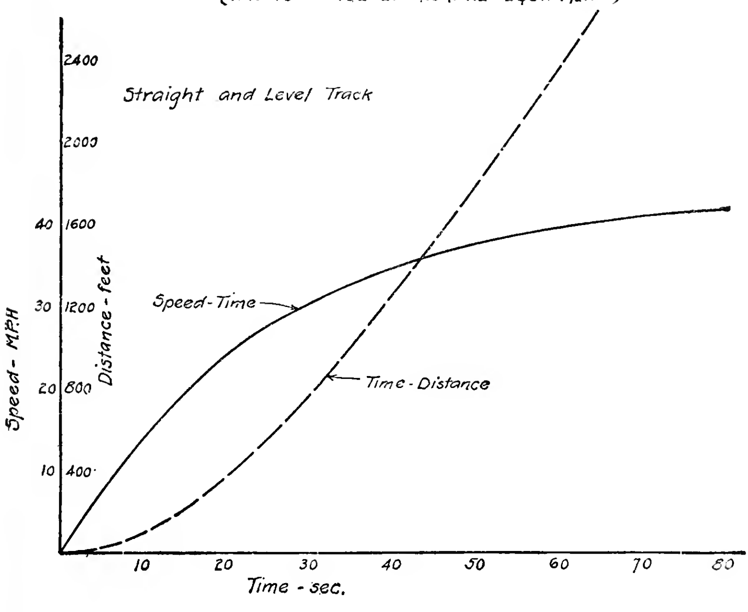
The basic times and distances for braking are, for the 1906

(PM) equipment: 650-foot emergency stop in 21 seconds; service stop in 1470 feet and 40 seconds—both from 40 miles per hour. As seen from Fig. 27, the maximum speed does not exceed 28 miles per hour. The corresponding stops from 40 miles per hour for the 1916 (AMUE) equipment are: 380 feet in 11 seconds for emergency, and 580 feet in 16 seconds for service. For all other speeds the braking distances are assumed to vary as the squares of the speeds and the times directly with the speed. The time of

FIG. 26.

SPEED-TIME AND TIME-DISTANCE CURVES.- ACCELERATION.

NEW YORK MUNICIPAL RAILWAY—1916.
(HAVING AMUE-E&L. BRAKE EQUIPMENT.)

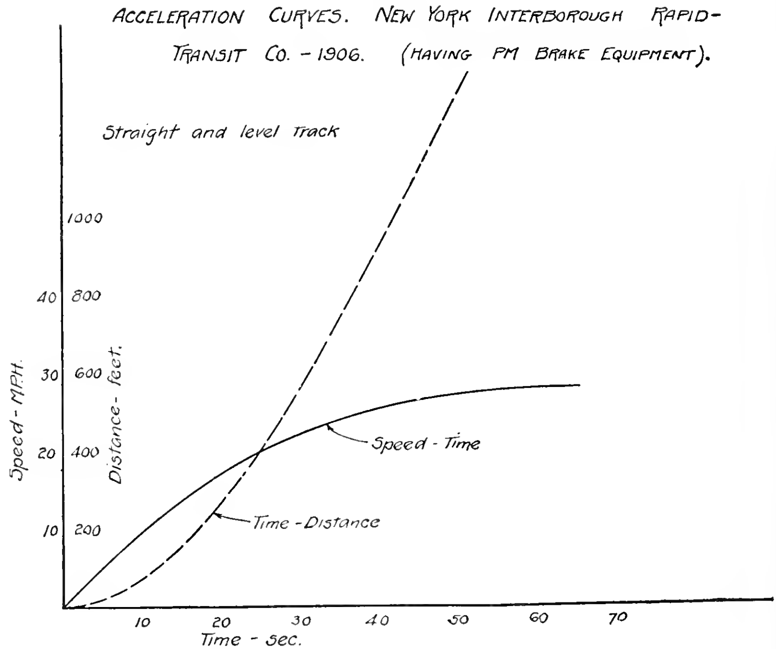


station stop is taken in every case as 20 seconds. The "station" headways (H_s) of Fig. 19 are the values used for the modern performance shown by Figs. 24 and 25. Headways similarly determined are used for the curves of 1906 train operation.

Fig. 28 compares the "running" and "station" headways for modern equipment with those of 1906. The train length for each case is approximately the same, which eliminates any uncertainty due to the influence of this factor. The minimum "running"

headway required for modern operation is only from 63 per cent. (at 60 miles per hour) to 65 per cent. (at 30 miles per hour) of that required for 1906 operation. The minimum " station " headway required varies from 63 to 72 per cent. in like manner. All of this may be summed up by saying that modern train control equipment has cut down the minimum headway required for the movement of trains to less than two-thirds of that required ten years ago.

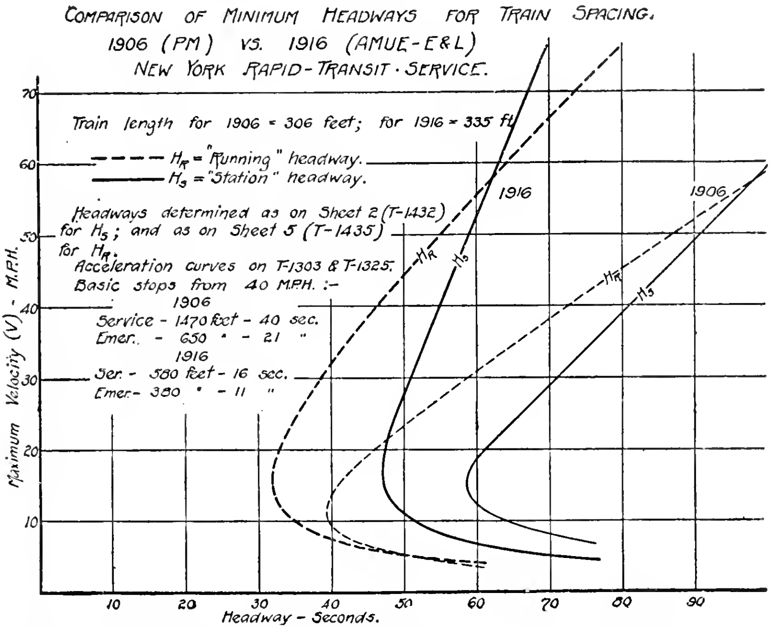
FIG. 27.



It is seen from Figs. 24 and 25 that as the station spacing is increased the traffic acceleration is also, which means, in turn, that the traffic volume for any given period is enlarged. This is for the reason that the time spent running at the maximum speed becomes a larger portion of the total time a train is on the road, and the average speed over a given district becomes correspondingly higher, as the station spacing is increased. The practice of having trains stop at alternate stations or groups of stations—" skip " stops, in other words—is based on this relation.

These curves also show that as the maximum running speed is increased the traffic acceleration becomes greater, but at a decreasing rate, until finally, at some critical speed value, it actually starts to fall off with a continued increase in speed. This is best illustrated by the curves for one-half-mile station spacing. The critical speed for the 1906 equipment and this station spacing is about 25 miles per hour, and that for the modern equipment about 35

FIG. 28.



The minimum headway required for train operation to-day is but two-thirds of that required ten years ago, due to the introduction of modern control equipment.
"Station" headway (H_S) determined as on Fig. 18.
"Running" headway (H_R) determined as on Fig. 21.
Figs. 26 and 27 are the bases for acceleration values.

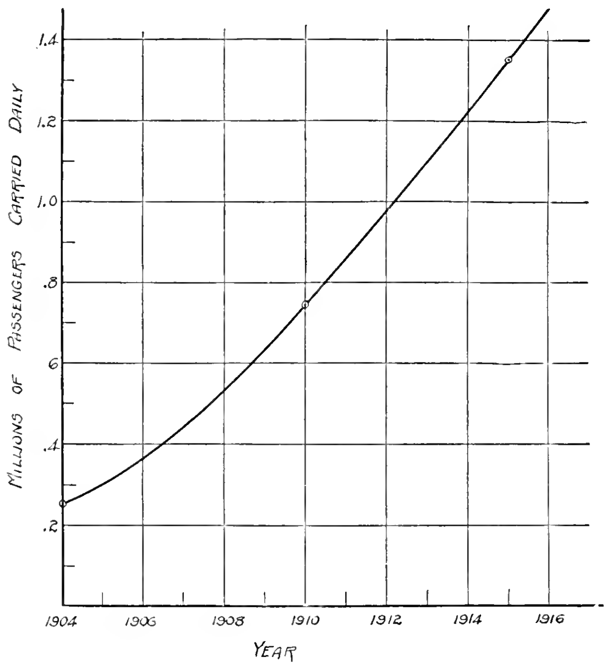
miles per hour. To operate at speeds greater than these critical values is actually to reduce the traffic acceleration and correspondingly the traffic capacity. As the station stops are spaced farther apart this critical value for speed becomes greatly increased. The reason for this peculiar relation is that the traffic acceleration $(\frac{V_s}{H_s})$, though directly proportional to the average speed V_s which increases with an increase in the maximum speed, is inversely proportional to the headway, H_s. A point

is finally reached where the increase in headway, H_s, due to higher speed is proportionately greater than the increase in average velocity, V_s, and the net effect on the quotient is to lower it. That is to say, the gain in average speed due to increased maximum velocity is more than offset by the increased headway, actually causing a lessened rate of traffic acceleration.

The relative performance curves on Fig. 24 show that modern

FIG. 29.

INCREASE IN NUMBER OF PASSENGERS CARRIED DAILY, BY THE INTERBOROUGH RAPID TRANSIT COMPANY SINCE OPENING IN 1904.



brake apparatus as compared with that of 1906, has permitted an increase of 50 per cent. in *the number of trains* to be handled with the same roadway facilities in the way of number of tracks. While it is true that the modern motor equipment provides a higher maximum speed and a rate of acceleration somewhat better (14 miles per hour for the first 10 seconds, as compared with 10 miles per hour—see Figs. 26 and 27) the train length is also greater, con-

tributing toward an increased headway for the modern condition, other things remaining equal. This increased train length means, however, more passengers per train; therefore, the best overall comparison is found in the relative passenger-mile performance curves of Fig. 25. These show a gain in capacity of from 300 to 350 per cent., due to the use of modern equipment, with unchanged roadway facilities. This great advance in the transportation service, and, therefore, in the value of the railway properties which carry this service, depends on, more than on anything else, the strides made in the science of train control. For the present status of this science has rendered possible high rates of retardation started in trains of greatly increased length with a minimum loss of time, heavy cars with a large load capacity, and greatly reduced headway between trains.

Figs. 24 and 25 are based on the so-called old AMUE brake equipment, which involves an application reflex time of two seconds more than the latest equipment. The curves were prepared before this recent improvement was made and are, therefore, already not quite up to date in portraying the traffic capacity now possible.

Fig. 29 pictures the strides which have been made by the New York Interborough Rapid Transit Company in the number of passengers handled daily since its inception in 1904, and serves well as an interesting practical summary of the vital relation of train control to the value of railway properties.

CONCLUSION.

Trains cannot be moved unless they can be controlled. To turn loose the tremendous power of modern locomotives without adequate means for controlling it would be similar to generating a high steam pressure without suitable provision for containing it. The effectiveness of control will determine the speed and number of trains. It will determine the number of cars which may be successfully operated in each train, as well as their weight and variation in weight from the empty to the loaded condition. The word *determine* has been used. But, as a matter of fact, the advancement in the science of train control, arising in the types of apparatus designed to meet ever-changing requirements, has kept pace with, and is actually abreast of, the increasingly severe operating conditions. Therefore, the advancement in railroad effi-

ciency, which in this respect has placed us ahead of every other nation on the face of the globe, has been *permitted*, rather than determined, by the progress made in train control equipment.

Further advancement will also be permitted in just the same degree that the railroads continue to avail themselves of the advantages offered by modern equipment for train control; that is, amazing strides in furthering the economic worth of railway properties, to the public and stockholders alike, can be made by applying intelligently to the science of train control for solution of the weighty traffic problems of this day.

The attempt of this paper has been to point out more the *potential* value of, rather than the absolute necessity for, improved types of train control apparatus. This is not intended to be a claim that increasing the capacity of a railroad by any means will increase the supply of business, whether the means be double-tracking, improved methods of train control, or any other. Increased capacity for a railroad no more increases the business of the railroad than does the enlarging of a tank increase the water it originally contained. Putting in a second pipe line does not add to the content of an oil well—it merely makes possible the transportation of a larger output if the larger output be there. Similarly, providing improved traffic facilities for a railroad will not supply the traffic, but such provision will meet increased traffic demands. And all may rest assured that the demands will always precede the extension in capacity. In short, the science of train control solves *weighty* traffic problems. Where there is no problem obviously there is no solution required.

Unfortunately, the significance of the problems themselves, quite apart from their solution, is not appreciated by many who are directly concerned with them. There are evil results attendant upon the use of the single-shoe-per-wheel type of foundation brake gear; the use of air brake devices in service far beyond their designed capacity; the operation of trains with effective braking ratios widely varying from one portion of the train to another, due to leakage, lack of uniform piston travel, car loading, etc.—upon all of these and many other malpractices.

The extent of the evil results herein arising is beyond the ken of only too many whose interest it is to know of this indirect tax—this improperly invisible drain on the economic wealth of our transportation systems and, therefore, finally, on the commonwealth.

In other instances these results are accepted by many railroad managers as a matter of course; as necessary evils indissolubly associated with the operation of trains, and to be paid for as unavoidable elements of the cost of transportation.

The purpose of this paper has been to review the factors involved in railroad capacity and to show that train control can be made the most effective and profitable of all (in fact, it is so now); still, there is as much to be gained in this direction as has already been done. Some say we are getting along all right with what we have, and this may be granted, particularly as regards safe operation, but safety is now being had largely at the expense of economy and capacity. Is this wise? Is the investor satisfied? I think not when I see such efforts as are being made to increase capacity by "bigger power," greater capacity cars, etc.—the larger factor being neglected for the smaller.

What we now use generally is good, but what only a few are using is better, as they have proved. All the factors should advance at an equal pace if a rounded-out return is to be had. It is not the intent to condemn the old train control systems any more than progress in any direction may be considered condemnatory of that which has served its time and has been the pioneer of a better thing.

Wherever increase in capacity of a road is the desideratum it will pay to give the train control factor the most intelligent consideration. In other words, I intend only to set this up as a business proposition to be considered according to strict business principles.

It is high time that due study and thereby due appreciation be given to the underlying and, it is true, intricately interrelated causes for operating troubles, because their removal establishes an economic gain of a dual nature: First, the elimination of expense directly due to these troubles, such as damaged lading and equipment, delays, etc.; and, second, the extension in traffic capacity permitted without a corresponding increase in operating expense.

The adoption of adequate train control equipment will do more than any other means possible to remove operating troubles, and, with existing right-of-way facilities, to provide for the extension in traffic capacity which will make possible the realization of the utmost efficiency in that most wonderful of our industries, transportation by rail.

How a Large Manufacturing Company Disposes of Its Old Metal. J. M. BATEMAN. (*Proceedings of the American Institute of Metals,* September 11–15, 1916.)—One unaccustomed to the handling of raw material in large quantities little realizes the amount of work entailed in trying to dispose economically of the immense amount of waste incident to the carrying on of manufacture in a factory so large as the Hawthorn Works of the Western Electric Company. When, however, a monthly raw material input approximating $1,500,000 in value is considered it is not difficult to conceive the amount of waste resulting from its use. A somewhat clearer idea of the amount of material involved may be obtained from the figures representing the approximate monthly averages of the large items of junk disposed of. Brass, 100 tons; copper, 180 tons (125 tons from the cable, rubber and insulating shops); German silver, 17½ tons; iron and steel 89 tons; solder skimmings, 4 tons; lead, 833 tons. All these materials are carefully separated, cleaned, and baled in the form in which they command the highest price.

Experiment With Mercury Jet Interrupters. C. E. S. PHILLIPS. (*Proceedings of the Physical Society of London,* vol. xxvii, No. 4, August 15, 1916.)—The experiments here recorded were undertaken in the attempt to ascertain the form of the mercury column issuing from a hole in the side of a rotating drum that is continuously supplied with mercury by centrifugal action. Incidentally a new form of interrupter is introduced in which the interior is visible through a window in the lid. The arrangement forms a suitable apparatus with various forms of orifices and metallic contact segments, and an account is given of work in that direction. As it is important to insure the cleanliness of the mercury in interrupters of this type, the copper usually employed for the segments is replaced by tantalum which for many reasons is preferable. It is not "wetted" by mercury, it remains clean and bright indefinitely, and its high melting point renders it lasting.

Experiments with various forms of orifices are described, and it is pointed out that the issuing stream is only slightly affected by this means. An explanation is given of the fact that a vertical slit orifice will not produce a ribbon of mercury, and no matter how much the diameter of the orifice is increased beyond about 2 mm., the cross section of the mercury column remains unaltered. A method is described, however, by which a much larger stream of mercury can be obtained from the rotating drum if necessary. Brief reference is made to experiments with various volatile liquids in suppressing the flare which occurs when the mercury columns leave the contact segments. The three well-known substances which are most effective in this respect are coal gas, hydrogen, and ether. It is pointed out that experiments of this nature are necessary in view of the wide use now made of mercury interrupters in X-ray work.

ADMINISTRATION: ITS PRINCIPLES AND THEIR APPLICATION.*

BY

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INTRODUCTION.

1. OCCASION seems to exist for an attempt to clarify and systematize our ideas in this direction and to reach some acceptable conclusion as to the general nature of the fixed guides by which executive responsibility may most surely be discharged with success. We are living in an age which is making unprecedented demand for administrative ability—a demand not met by the supply of natively endowed administrators. There are, of course, a large number of such—both men and women—and there are, on the other hand, a large number of individuals who by reason of temperament, character, and education,[1] or what not, could never adequately fill an executive position, no matter how fully tutored to assume its responsibilities. But between these two extremes there is a much greater number of men and women than in either of the other classifications which, it is believed on the evidence of countless instances, represents latent capacity and is susceptible of easy development from the potential to the utilizable kinetic. It is this latter group which is especially addressed, although the born administrator will not suffer by having his ability defined and placed in intelligible and convenient order. The number of those who should be vitally interested may be closely approximated when we consider that the range of the applicability of administrative principles reaches from the household to national government itself, and that within a large administrative unit there are lesser units to be guided—first, in the interest of the institution's efficiency, and then as

* Communicated by the author and based on a paper read before the Summer Conference at the U. S. Naval War College, Newport, R. I., in 1913.

[1] NOTE.—The word "education," as here used, is not to be interpreted as mere book knowledge, but is intended rather to convey the idea of that breadth of view and understanding and mental grasp which is not denied the unlettered.

preparation for the assumption by the individual of higher and higher administrative positions—for promotion, in short. Such is the genius of all democratic institutions that no one is denied the rewards of demonstrated ability to handle men and wring results from an organization.

In the quest for information on the general subject of administration for purposes of study preliminary to its discussion it was a great disappointment to find that little was available. There were plenty of misleading titles in the indexes consulted, but the books and treatises under various captions involving the term "Administration" usually discussed "Organization," although in most there were here and there what may be characterized "Administrative gems." There is evidently considerable confusion as to the precise meaning and applicability of these terms, or, at least, an unsatisfactory differentiation between them. I am not sure that, in the following discussion, I will not be guilty of the same confusion in my view of which I am disposed to accuse others; but, if that proves to be the case, it may be explainable as concerning those points on the border-line of the subject where they blend almost imperceptibly into equally border-line points of organization. In any event, the writer's efforts will be gratifyingly rewarded if his readers are stimulated to think along the lines indicated, to test the truth and applicability of the enunciated principles, and, in the case of the proved administrator, to judge whether or not his success is in large measure attributable to an unconscious application of the enunciated principles.

As intimated above, the question of "Administration" is inextricably intertwined with that of "Organization," for nothing that is not organized can be administered, and nothing can be permanently organized that is not susceptible of administration. Yet the terms are not interchangeable and should not be confused, as they seem generally to be, if many articles on these subjects are any criterion. In spite of this interrelation, they are terms distinguishing distinct things and should be so separated in discussion.

Nothing conduces to this end so much as to define one's premises, and it seems well, therefore, at the outset to express my understanding of the key-words as a basis for what is to follow

DEFINITIONS OF KEY-WORDS.

2. The term "Administration," as comprehended in the subject of this paper and by which discussion will be guided, may be defined as: "The act (or acts) of administering; direction; management; government of public affairs; the conduct of any office or employment" (Century Dictionary).

While the term "Administration" is defined as above, narrowly, it always carries with it the idea of accomplishing its ends through the mediation of agents of various degrees and numbers, according to the kind and size of the organization, in behalf of the central figure—the integrating factor—the co-ordinating unit, who in turn represents the public directly.

"The administration of government, in its largest sense, comprehends all the operations of the body politic, whether legislative, executive, or judiciary; but in its most usual, and perhaps in its most precise, signification it is limited to executive details and falls peculiarly within the province of the executive department" (Hamilton, *Federalist*, No. 72).

"Sometimes (however) the term 'Executive,' which strictly means an authority which puts the laws in force, is opposed to the term 'Administration,' which (as above stated) implies the performance of every other sort of immediate government act . . . . " (S. Amos, "Science of Politics," p. 99). It is this latter meaning which is accepted for present purposes.

3. "Organization" is the act of arrangement or *an* arrangement of related interdependent enterprises into a group with such system as will enable, and make it possible to compel, each to co-operate harmoniously with the others in the accomplishment of a common end.

There are two processes by which organization is attained—organization by accretion, *i.e.*, from without, as the growing of separate things into one; organization by differentiation, *i.e.*, from within, as exemplified in the biological development of the human race from a single cell. In the creation, upbuilding, and maintenance of most institutions both of these processes are operative.

Here we arrive at differentiation of the above terms by way of recapitulation. Organization is the substance; administration the form. Organization is the instrument; administration the method of employing it—the integrating, guiding, and energizing force.

4. Coming now to the term "Principle," I find it defined in the Century Dictionary as: "That which is professed or accepted as a law of action or a rule of conduct; one of the fundamental doctrines or tenets of a system . . . ." Expressing it in another way, "Principle is that on which something else depends; and this both for an original law and for an original element" (Sir W. Hamilton, Reid, Note A, E. 5, Supplementing Dissertation), and thus we see that there are both regulative and constitutive principles. It is only by very careful observation that we are able to extricate precisely the general law which is the expression of the regulative principle, and yet it is the given task not only to do this but to apply it.

DERIVATION AND HISTORY OF DEVELOPMENT.

5. In the beginning, of which the pioneer period of the United States may be taken as a near example, each individual worked in his own interest and was all-sufficient unto himself for the necessities of life. There was no relation or interdependence between individuals except as the family came into existence and supplied the source from which the administrative idea was derived, the male parent assuming authority.

Then came the stage in development which was marked by an accentuation of ability in one or another of the personal enterprises supplying the needs of life, and this change was accompanied by barter. *Pari passu* with the extent to which it was possible to make such personal arrangements, attention to the barterable article subsided on the side of custom (patronage) in the interest of giving more time and energy to the production of a barterable commodity or the development of a barterable ability of its own. And so with the increase of population and the more complicated demands of existence specialization in the social body progressed until each art or undertaking was represented by so many that competition supervened.

Then came the union of forces to supply the growing demand —a banding together of units for complete production in themselves without interdependence other than in certain obvious economies to be mutually realized, such as common workshop and business representative.

Following this came the division of the task among the members of the group wherein each unit of work constituted a part of

the whole only, and thus the idea of specialization was renewed, the size of groups increased, organization became imperative, and administrative systems were required. But the underlying philosophy in the old system of specialization was *laisser faire*. Each individual was left with the responsibility for doing his particular job practically as he thought best, with little or no help from the management. To-day a movement is on foot to bring the workman—the individual—out of this isolation and teach him to perform his part not only in such a way that it will dovetail with that of others but in accordance with the rules and laws of a science or art—Scientific Management.

6. By way of recapitulation we may construct a verbal triptych:

First, the individual, standing clear, sufficient unto all his simple needs, but beginning to develop a special ability.

Second, the individual lost in a maze of associated effort to meet communal requirements.

Third, the individual regaining his identity in training his abilities to the point of highest efficiency, while at the same time individual effort is being welded—not merely in associated, but interdependent and coöperative work.

Now that the last of these pictures is on the screen, we will at all times in the extension of civilization have in our midst examples of each one of these several successive steps in development.

7. The impelling influences to changed conditions in performing the world's work and meeting the growing demands and economic problems were increased efficiency and more rigid economy—the minimizing of waste, which were only to be had by the amalgamation of similar but interdependent industries or enterprises into corporate bodies under one management, calculated to secure harmonious coöperation in the accomplishment of a given end.

8. The principles of organization and administration have not been newly discovered; they have been rediscovered as in the history of so many unwritten fundamental laws governing the various relations in life. They were realized and given heed in the early Christian era and probably long before. Since then they have again and again exercised their influence and slipped

into disuse beneath the surface of the bubbling caldron, only to reappear and force themselves upon the struggling world.

In only one type of organization have they held uninterrupted sway—the military—and from this civil institutions have frequently derived their inspiration when formulating systems of administration.

The growth and effect of administrative machinery are attributed, therefore, to the enduring truth of

THE EVOLVED BROAD PRINCIPLES OF ADMINISTRATION.

9. "What deep joy fills the mind of the philosopher when, throughout apparently inextricable confusion, he can trace some great principle that governs all events, and that they all show forth" (Channing, "Perfect Life," p. 109).

Successful administration is not found in "the great personal or individual achievements of any one man standing alone and without the help of those around him." It is found in that type of coöperation in which each member of an organization "performs the function for which he is best suited (preserving his individuality and supreme in his particular function) . . . and yet is controlled by and must work harmoniously with other men" (Taylor). Such harmony of action, however, is not a happening of chance or without basis. It is assignable to a certain philosophy which has been wrought out of old knowledge so collected, analyzed, grouped, and classified that it constitutes a science. It is due to a mechanism, which has gradually evolved and each element of which is characterized a principle. Let us separate and examine the principles.

THE PRIMARY OR CONSTITUTIVE PRINCIPLES.

First.—A single mind in control from which the plan of action and the directing authority must emanate.

Second.—Subdivision of delegated authority in conformity with the branches of the organization.

Third.—The recognition of areas of discretion corresponding to subdivisions of authority, but within the range of loyalty to the end in view (mission).

Fourth.—The determination of a mission and the promulgation of a general scheme or plan for its attainment.

Fifth.—The exercise of a system of inspection.

These are formulated in deference to the motives which study and experience show to influence men. It is true that laws formulated on such a basis owing to the fact that the very complex organism—the human being—is concerned, "are subject to a larger number of exceptions than is the case with laws relating to material things." And yet the above principles are sufficiently broad to give play to flexibility. Moreover, "laws of this kind which apply to a large majority of men unquestionably exist, and when clearly defined are of great value as a guide in dealing with men."

10. *A Single Controlling Authority and Subdivision of Delegated Authority.*—The purpose of organization and administration as shown under the history of the development of the idea was increased efficiency and greater economy, and this could only be attained by concentrating under the leadership and harmonizing force of a directing centralized will. The provision for this office is the predominating feature of all modern organization, and the administrative principle it represents is given place throughout the lower reaches of every organization. Each division and subdivision has its head, and descent of authority and ascent of appeal pass through the subordinate heads of each step in the organization from or to the highest executive authority in the institution, although the head of each division or branch exercises authority over the subordinates in his branch of the establishment to whom he entrusts the execution in detail of the separate task, in the general plans, assigned him. He also assumes responsibility for discipline and results within the field of his supervision, exacting obedience on the one hand and guiding the activity of his immediate subordinates in such wise as will contribute most surely to the realization of the object decided upon in accordance with the plan formulated and transmitted to his subordinates by the executive chief, which in turn is dictated by the policy adopted by the management in its deliberations.

11. The object underlying this principle of administration is coördination, and its mainstay is discipline. Having subjugated the spirit of subordinates to the influence of the guiding intelligence, it remains to impose a common mission and advise as to the plan for reaching the objective. In fulfilling the conditions of this latter requirement where many divisions and subdivisions of work are to be coördinated it may be necessary to go into con-

siderable detail concerning the various tasks to be accomplished, even to the last link in the chain of administrative consequence. But in the distribution of tasks of progressively decreasing importance a double precaution must be exercised that each subordinate in the system of organization is not charged with greater responsibility than he can efficiently supervise—nor yet a task smaller than his capabilities. The one error of judgment defeats efficiency; the other defeats economy.

When professional capabilities and professional character are at fault in a subordinate, or if for any cause inadequacy to a reasonable standard of productivity develops and results fall short of expectations or needs, there are but two ways out of the situation, depending upon the nature and degree of the shortcomings: not by the meddling of a superior in duties which belong to another, but by instruction or by elimination of the inadequate individual and the substitution of one more capable—instruction where removal is impossible or there is hope of developing efficiency, "but for downright incapacity" wilful refractoriness and conscious disloyalty "there is only one remedy, and that is removal from office." In this connection, where it is merely a question of incompetency, the conception of a new division in the organization of an institution which is at once an employment office and clearing-house for personnel is based on the reasonable assumption that relatively few individuals are utterly useless; that every one has a particular niche in which he will work to the best advantage of himself and his employer; and that often an individual is wrongly placed on the occasion of his initial employment. If an employee is inadequate in his first assignment it may be found that he will give superior service in a second or third position, and it is worth the trial in the interest of justice to the individual (that he be not condemned off-hand) and in the interest of industrial economy. The idea is a new one, but experience with it justifies the belief that it is a practical instrument in the handling of men and is entitled to a permanent place in the industrial world. The "Scientific Employment Plan" was very interestingly presented some months ago by Burton J. Hendrick.

12. *Area of Discretion.*—As seen, the scheme of organization provides for lesser leaders—heads of divisions and subdivisions. It is here that the opportunity for so-called areas of discretion is

found, and it is necessary, in the interest of efficiency and economy, that advantage be taken of that opportunity to give play to initiative, which can be a distinct asset. The theory of the necessary existence of areas of discretion lies in the fact that unforeseen conditions and problems incident and collateral to the business in hand are continually arising in each branch of the work and must be met and solved without avoidable recourse to the higher administrative head. It also lies in the fact that the methods to be adopted in accomplishing a given part of a common task should ordinarily be left as far as possible in the hands of the division head. There is sound reason for this on the side both of the superior and of the subordinate.

In the case of superiors, while they may reserve the right to directly control as many details as they can efficiently handle, any undue interference in the field of responsibility assigned to subordinates absorbs their energies in illegitimate channels at the expense of their proper duties and thus jeopardizes the effectiveness of the general system. Such action upon the part of superiors constitutes confiscation of prerogatives and misappropriation of time and abilities and energy.

In the case of subordinates the consciousness that they are being held responsible for results alone and that their hands are free to direct the activities of their respective branches according to their judgment and ingenuity engenders a healthful sense of their importance to the big end in view and inspires an interest and loyalty which are valuable assets of the institution.

In the one case the central administrative hand is infinitely strengthened by confining himself to the conceded limits of his office. In the other case repeated interference from above dampens ardor and reduces service to pure perfunctoriness, if nothing worse.

It is, of course, sometimes, in emergency, necessary to assume temporary control outside of the area of superior action which the administrator may have outlined for himself, but occasion for this should arise only in an emergency during the absence of the subordinate concerned or when the skill and reliability of a subordinate are in question.

Similar to the limitations of central administrative activity, the area of discretion of subordinates is also limited. It is limited to " the right to do *right* as you (the subordinate may) please "—

the right to act and exercise judgment within the range of loyalty to the policy and mission and plans of the institution with which he is identified.

13. *A Common Object and General Scheme.*—Here, in turn, and finally, we come to the thing for which organization and administration are brought into being and perfected—a common purpose or a common object; the something of mutual concern in the interest of which coöperation is demanded. Herein is found the force that binds superior and subordinate. The underlying basis of liberty of action in subordinate positions is "loyalty to the scheme, and this, of course, demands that there be a scheme to be loyal to," and that the scheme be intelligibly communicated through all the ramifications of the organization.

14. *Inspection.*—Inspection is a procedure upon which, as a stimulant, the continuous effective and guiding activity of the principles of administration in great part depend, and yet, as it is an important part of every administrative system, it will be discussed at this time and may itself be accounted a principle, as so much of success rests upon its proper exercise. It is one of the sources for the gratification of the "honor-motive" in *esprit de corps,* to be discussed later; it stimulates a persistent positive activity and defeats that otherwise progressive passive lapse from established standards of efficiency and economy; it maintains the objective of the administration clearly before the members of the organization; it constitutes a channel to publicity; it furnishes comparisons which inspire the manager to seek to improve methods and enable him to alter his standards of maximum and minimum performances, both for the individual and for the several branches of the organization; and it brings to bear on the administration a vision and understanding not dulled by the familiarity incident to daily contact with the subject or matter, but acute to defects and praiseworthy features alike and capable of discerning opportunity for improvement.

15. The agencies of inspection are not limited to a formal office, and none should be neglected. "It is not enough for the head of a system of administration to express his resolution in regard to a proposed action" (Rodgers, p. 17). In addition, the execution must be supervised to insure active fidelity to the plan, and in small institutions the principal himself will be able to fill the office unaided. He must, however, always be a party (albeit

an independent party) to the function of inspection, and in this fact is emphasized the prerequisite that the administrator should be familiar with the technical details of his organization.

16. The condition of the relations between interdependent internal branches of the organization and between those and the interested public; the periodic conference of heads of divisions, together with the chief, and their daily reports to him concerning unusual or important matters or occurrences; the statistical comparative study of other similar administrations; and the use of publicity are other forms of inspection automatic in their assistance to the administration. But, valuable as those are in their limited scope, none of the foregoing contributions to the principle of inspection relieve the urgency of the demand in large institutions for the exercise of the function by an inspection office or staff which shall be independent of the strictly executive branch and beyond the control of its subordinate members, and through which the administrator may keep in touch with every branch of his responsibility.

CONDITIONS UPON WHICH THE PRINCIPLES OF ADMINISTRATION DEPEND. THE SECONDARY OR SUPPORTING PRINCIPLES.

17. "The mechanism of management must not be mistaken for its essence or underlying philosophy. Precisely the same mechanism will in one case produce disastrous results and in another the most beneficent. The same mechanism which will produce the finest results when made to serve the underlying principles of scientific management will lead to failure and disaster if accompanied by the wrong spirit in those who are using it" (Taylor, p. 128). Though this truism was thus expressed by one of the foremost exponents of scientific management, it is in its very neglect to give adequate practical recognition of the fact that scientific management has failed. Many of those using it have displayed too single-minded an interest in material ends—have regarded men as mere machines, and have too often overlooked the human factor involved, which, "as in everything, is essential." Applied psychology is a closed book to them and to most administrators. "Unhappily, it is our habit not to study the psychology of the peoples with whom we have to deal, but to watch and react upon the shifts of circumstances" (E. J. Dillon, *The Fortnightly Review*, November, 1915).

The Spirit of the Administrator.—Laws, rules, and orders are important and unavoidable, but they should be limited to such as may be absolutely necessary without tying the hands of the governed too closely, and human nature must be taken into account in their formulation. Too many rules produce confusion and invite disobedience, and, moreover, rules do not of themselves accomplish good administration. The character of the administrator determines that. The personal element comes in here and is reflected in the administration. The administration is the gauge of discipline, and the degree of discipline is the expression of the quality of the personal element. The wish and tendency of the normal individual are to do right, and there is little fickleness about such a material thing as an organization. When affairs go wrong, therefore, it is very much more apt to be the administration, not the organization, which needs improvement or correction.

18. There are certain underlying conditions which emanate from the spirit of the man (administrator) upon which successful administration depends. This is shown not only in his bearing toward his subordinates and the manner in which he approaches the functions of discipline and inspection, but the consistency which he observes in his personal conduct and administrative control of others.

19. *Forms of Ceremony.*—The recipient of authority in any system of administration must not be left unaided in that authority. Reference is not here made to rules and regulations, which should only be employed as a last resort, but to moral force, which is expressed in the widely observed influence of one man over another, based on a conception of greater ability in one by the other—an unconscious intellectual assent to superiority, and which is preserved by certain forms of ceremony tending to exalt the prestige of the executive head—some, the outward show, well recognized; the nature of others less appreciated.

20. The former consists of *artificial aids*—the stringent prescription of forms of respect in military life, such as differences in uniform, the salute, and the guard of honor, and in civil life the etiquette and courtesies demanded of one (the effect of which is sometimes enhanced by little difficulties of access) in his intercourse with an official superior. These are not vain show. They are customs, the observance of which is obedience in spirit, and "they conduce to discipline as conventional good manners . . ."

21. The other forms of ceremony which are conditions to the continued operation of the dormant administrative principles involve: *qualities of temperament,* such as patience and self-control; *qualities of mind,* such as consistency, self-reliance, and a lively sense of justice; *habits of conduct,* such as dignity and reserve of bearing, though not stripped of "the amenities of cordiality or the cultivation of good cheer" within proper limits; and the practice of keeping one's own counsel to the extent at least that one's deliberations, doubts, and official acts may not fall "unnecessarily under the scrutiny of one's subordinates." It is given to few men to decide a question of moment correctly in off-hand fashion without some deliberation. Patience and decision are two very important qualifications of an administrator, but they must be carefully adjusted, for they are in a sense antithetic, and the former, if exaggerated, will produce the effect of weakness. There should be no appearance of seeking approval or of dependence upon the views of subordinates, although encouraging them to express their opinions. The aim should be, rather, to lead them to seek advice and to regard the administrator's invitation to share his counsel as a privilege; to develop that mutual confidence—the feeling that they are all working for the same end and will share in the results—which should exist between a leader and his men.

Every administrator of large institutions who does not come directly in contact with a majority proportion of the personnel, particularly the lower ranks, must be careful in what manner he indicates his disposition of kindliness toward them. It is to be presumed that he will at least deal with them along the line of plain justice. His personal and official acts at the beginning should demonstrate his intentions, and his consistency in that direction should be a matter of course. There should be no demagogic appeal for popularity by an offer to adjust all difficulties. The assurance is but "a flash in the pan" in the direction of promoting contentment. The attempted execution of the promise breeds unrest and ultimately discontent—the very opposite to what was intended. But this is not all. The offer is translatable into an invitation to insubordination, which, in the first accounting, brings trouble and difficulties in the path of those upon whom he depends for the efficiency of the subdivisions of the organization and, in the last accounting, brings trouble and

ignominy upon himself—if not because of the failure of his administration, then because he is brought face to face with the impossibility of redeeming his promise—because, sooner or later, he is discovered as unable to stand with his head straight and his hands clean by the test of his own estimate of a "square deal." In one grand stroke such a man announces himself a panacea for all ills—and little ills at that—which increases their number, when he might to more purpose leave some of these little ills for the subordinate leaders to straighten out and fare infinitely better in so doing. "You can fool some of the people all of the time and all of the people some of the time, but you can't fool all of the people all of the time." To announce such a purpose as that of which I have been speaking may be justified in politics, but it is hardly far-seeing honesty or conducive to continued smooth running in an administration.

22. These ceremonial elements and ceremonial "don'ts" indispensable to successful control of an organization represent the spirit and are inseparable from the practical form of the function. They may seem at variance with the prevalent *spirit of democracy*, but there is that within the human nature of everybody, no matter what his station in life, which is favorably excited by a certain degree of pomp and show, and when this is governed by tact and discrimination (without bombast) it may be exercised effectively within the bounds of toleration and well short of resentment by even the strongly socialistic. The differentiation of self need not be obtrusive, and, while preventing that fatal suspicion among subordinates that the leader is no better than they, it "secures an ascendency which would not otherwise be procurable."

23. *Discipline.*—The impersonal attitude of mind toward offenders in the exercise of disciplinary authority is extremely important—not only as being the proper attitude, but as a means to easing discipline and robbing punitive measures of their undesirable sting. Most men who dance are willing to pay the fiddler when their attention is called to the debt, but in inflicting punishment it should be done with the idea of teaching a wholesome lesson and in such a way as to deny the victim any possibility of raising the thought that authority is arbitrary and tinged with animus or of engendering a lingering sense of resentment and an idea of persecution. Past offences cannot be corrected; future offences can be prevented. Punishments should be awarded

solely to minimize the recurrence or commission of the same or similar offences by the same or other individuals. "Between the flourish of the 'Big Stick' and the appeal to 'Sweet Reasonableness' lie ages of progress. At just what point the use of force yields to the plea of justice, as the more effective means of guiding human conduct, it may be impossible to determine. But that there is such a point in social evolution, and that we have long since passed it, must be evident to those who will carefully weigh the evidence of history" (*The Public,* vol. xvii, No. 825, p. 73).

24. *Regulations and Rules.*—The administrator's relation to the established order, and rules and regulations necessary in any management of affairs, exhibits the rationale of the impersonal attitude of mind. He is not the government or the management (the board of governors or directors in a corporation). He is but the representative thereof—in such rules as he may promulgate himself by virtue of authority vested in him, as well as in those placed in his hands as from higher authority. In the first case his rules are in behalf of the management as certainly as if prepared by the management itself. Such rules, as soon as established, become the rules of the management, whether specifically approved by it or not, and any infraction of them constitutes an offence against the government or management and not an offence against the person of the administrator. It is true that some offences are so flagrant that the emotion of anger is difficult to control, but anger has no place in the official relation of an administrator and his subordinates, and it had better be given opportunity to subside before punishment is adjudged if justice is the aim. There is as much difference between forbidding certain acts and stimulating participation in right conduct as there is between a God who punishes sin and one who rewards virtue. In other words, "It is easier to maintain law and order where men look upon the law as a friendly guide than where they see in it only brute force."

25. *The Spirit of Inspection.*—Among many individuals the duty of inspection seems to inspire in them a new and strange spirit—new in the sense that it is abnormal to the degree of being antagonistic to their native feelings for fellow-officials or co-workers; strange in that they seem to be burdened with the necessity of unearthing some culpable error or omission, instead of

looking for evidences of efficiency and taking note of the features in which there seem opportunity for, or the possibility of, improvement. They seem to become possessed of the idea that the fulfilment of their task—the mark of their efficiency in the duty imposed—is unfavorable criticism. They make their office an unpleasant instead of a grateful duty—a thankless instead of a helpful duty—a source of irritation instead of an encouragement. It all depends upon the attitude of mind in which the duty is undertaken and the tasks approached—the interpretation of the purpose of the office, whether or not it is a successful inspection and an element in fostering administrative cohesion and loyalty. In the one case it puts the head of an administration and all under him (in the field to be inspected) on the defensive and resistant in the direction of the inspector's inquiry. In the other case it brings to the inspector's assistance the coöperation of the inspected and an openness and frankness in all matters of concern to the inspector. Such a reception would be accorded because of the hope of deriving the benefit of an eye fresh to the task of ferreting out defects overlooked by the too familiar eye of those who are constantly on the ground and, therefore, without perspective—because of the hope of eliciting approval or suggestions for improvement. It is the larger view which should be taken by the inspector, and he will then find himself in the best strategic position to carry out all the requirements—even the disagreeable, if so it be—of his office.

26. *Consistency in Policy and Executive Acts.*—There can be no question of the importance of consistency—in policy and executive acts—to successful administration. Efficiency to the extent that it rests upon contentment and sound progress cannot be secured without consistency, for that idea reflects certainty of aim and brings mutual understanding, which are at the bottom of coöperation. It makes little difference what a given policy may involve: if consistently followed, progress and development are inevitable. It makes little difference how rigid the discipline—how taut the requirements: if the discipline is consistent it will be a happy institution. Everything is run to-day as it was yesterday and will be to-morrow, and all hands know what to expect. At all times everybody knows what can and what cannot be done—what is expected of him and what somebody else will do—and can adapt himself accordingly.

27. *Esprit de Corps.*—Thus far the physical and intellectual and moral elements, the latter, so far as the principle is concerned, constituting and supporting administration, have been briefly discussed. There remains to be considered the collective moral element represented by the personalities of the subordinate members of the organization—the agency by which the administrative system is vitalized. The moral element exerts a most important influence for weal or woe, but usually the former under normal conditions and when the natural spirit of men is not perverted by extraneous interference. It is *esprit de corps*, or, in psychology, a force known as "motor-activity"—"the self-organization of groups"—which lies at the bottom of this collective moral element. It is the primitive disposition commonly manifested among men in association—"the blest tie that binds"—and has everywhere developed a code of "unwritten law and traditions more potent than statutes and regulations in welding into a consistent whole the somewhat incongruous elements" that go to form any organization like a large industrial institution, or an army, or a navy, or a nation, for that matter. "It *means* a revival of the principle of coöperation as against the principle of competition"—of unity of effort as against "the disrupting tendencies of opposing or selfish interests"—and is exhibited in the movement which is tending naturally towards integration, federation, and scientific management.

It does not embrace trade unionism which is essentially artificial—nor is it in any sense altruistic. Dr. Colin Scott argues, as abstracted by Ward,[2] that "the everyday experience of life shows that the efficiency of a man as a social animal or as a member of the community depends less upon his individual attainments than upon his power of adapting himself to his social environment." Within well-recognized bounds the cult of individualism is important as a stimulus to the fullest development of the best possibilities of one's native characteristics and capabilities, but it loses its value and means worse than nothing if it goes too far and does not in the end make for a more intelligent and harmonious collectivism—if it becomes translated into license and fails in deference to that essential community force which tends to hold every one in some relation to others and makes one's

[2] Ward, "The Psychological Bases of Esprit de Corps," *United Service Magazine*, N. S., 40, p. 390.

every act of greater or less negative or positive consequence to one's associates.

28. *Esprit de corps* is *engendered* by two motives, subscribing to the above observation—the desire to perform efficient service to one's group, and the desire to receive appreciation. If, as has always been recognized, *esprit de corps* is an enormous power in the interest of efficiency, binding associated individuals closely to each other and to the organization, and if the desire to do and the "honor-motive" are the two great motor-activities leading to *esprit de corps,* then those two motives should be planted and stimulated in the microcosm of every organization as valuable aids to their effective administration.

29. But when developed through the agency of these motives how is *esprit de corps* to be *preserved?* Even in this subtle commodity the principle of reciprocity—the give-and-take of life—is operative. The benefit of *esprit de corps* is an unconscious contribution to the welfare of the organization at the hands of the organization's collective membership, yet the "sympathy, enthusiasm, devotion, and jealous regard for the honor of the body as a whole" which it implies must be paid for. This is best done with the strengthening sustenance (also subtle) of just and kindly, though in no sense philanthropic or patronizing, attention by the administrator to the spiritual and material interests of the individual members, lest *esprit de corps* become transmuted into the trade-union spirit. It must be nourished by a gratification of the underlying motives to its origin. It must be nourished by such a manifest personal concern for the health, contentment, and progress of the men as will give ungrudging response to reasonable requirements in surroundings and conditions—as will offer a helping hand, should occasion require, and lead the individual to feel that he is an important part of the whole and a partner in its success.

And it must be nourished by tangible benefits appearing to emanate, and actually emanating, directly from the increased efficiency. The matter of profit-sharing is not as popular as it should be from this point of view—nor, so far as is known, has it ever been properly applied or theoretically developed to its feasible perfection. It involves loss-sharing as an inseparable counterpart. The operation of one should imply the operation of the other, but through the influence of artificial forces economic benefit and penalty have not been equally distributed. Profit has

been largely on the side of capital; loss largely on the side of labor. This is the genesis of labor's organization for protection and a preventable danger to *esprit de corps.*

30. *Publicity,* as another condition upon which the continued activity of the principles of administration depend, ranges itself with *esprit de corps. Esprit de corps* is not devoid of the possibilities or, even, likelihood of fault, and it may operate against efficiency unless carefully watched. It is the dangerous disposition it embodies, as a reflection of the perfectly proper administrative protection of individuals, to view loyalty in too personal and narrow a manner and to shield the unworthy, which must be guarded against. The influence of publicity serves this purpose. Publicity of one sort or another helps to place the object of our loyalty in relief and give it perspective, so that false *esprit de corps* becomes discernible and the threatened injury to the cause, in which all must share, is made clear.

THE ART OF APPLYING ADMINISTRATIVE PRINCIPLES.

31. The fundamental principles of administration, although derived from military institutions, "are applicable to all kinds of human activities, from our simplest individual acts to the work of our great corporations, which call for the most elaborate co-operation"—even to all social activities. The theory of their application is based upon the idea of unquestioned authority on the one hand and willing subordination on the other, with hearty coöperation throughout. This theory is just beginning to be understood, while the function itself has been a gradual evolution over a long period of years. However, be this as it may, no administrator can afford to overlook *the social democratic tendency* of the times, which, grafted on the long-existing spirit consequent upon "the doctrine of the political equality of all men," makes his task more delicate. He must be sensible of the real existence of this tendency as something to be reckoned with and adjust his methods accordingly. It is in this indirect way and to this extent only that cognizance can be given to the prevailing idea of social democracy in administrative operations, for its principles cannot be harmonized with the paramount principles of administration—the dominance of one directing power, with its counter-requirement, obedience. Autocracy in administration alone insures permanent efficiency—autocracy tinctured with an enduring sense of its many-sided obligation to others—not in-

toxicated with a consciousness of its power, and any refractory or unsympathetic spirit should be cut out summarily in its incipiency —not as a punitive act, denying the right of opinion to others, but as a preventive measure—a measure calculated to preserve harmony and insure coöperation—a measure in the interests of the unimpeded execution of the task. The idea of democracy may come into being and be properly conceded a place outside and above the administrative head—namely, in the authority which outlines the policy to be preserved and the objective toward which the whole organization directs its energies.

32. "Only the man who himself knows how to obey, who has learnt from personal experience how grievous an inopportune or superfluous order can be, and how inexpressibly hard it is, in such a case, to resist the impulse to revolt—only such a man will avoid blunders when he is himself in a position of command" (Von Spohr).[3] The art of command is to elicit a cheery and willing obedience; not to compel a slavishly servile obedience. "It is the first alone which conduces to happiness . . . . , insures a firm, unshaken discipline, and inspires men." So act as to rob obedience to an order of any semblance of servile submission, and this is best done by indoctrination. Orders must not be thinkingly or unwittingly used as a means to magnify one's own importance, and when necessary they should be unobjectionable in both matter and manner. Moreover, no more orders than are absolutely essential should be issued, for unless heed to this injunction is given all independence, all initiative, and all love of responsibility, so valuable in subordinates, will be killed.

33. Like the disposition to feel that nothing can go on without an order, any fondness for domineering must be checked, as this "leads to tyranny and incites insubordination." "What is wrong must be reproved, but not severely, not sharply, not in the form of censure, and an equal readiness to praise must be shown." "No man likes to be severely found fault with (particularly in the presence of others), but everybody is willing to accept instruction and does better another time. The man who has cause to fear fault-finding forswears initiative . . . and plays safe or keeps in the background."

34. With regard to order writing or written instruction, "every superior that finds he has been misunderstood should first

[3] Von Spohr, "The Art of Command," *Journal of the Royal Service Institute*, vol. 53, 1909, p. 56.

look for the fault in himself . . . ." The superior may know well enough what he wishes to order, but the question is: Do his words adequately express the idea—does his order or instructions—written or verbal—convey his intent clearly and concisely? No one can edit one's own expressions even in moments of quiet and leisure, and much less so at times of stress and excitement.

THE SUBORDINATES IN AN ADMINISTRATIVE FIELD.

35. Those who have carried a dinner-pail and worked for day's wages and also been employers of labor will tell you rightly that there is something to be said on both sides of this question of administration. The direction of obligation is by no means solely from above downwards. The obligation of the subordinate is just as pressing, and recognition of it will spell personal success in almost direct proportion to its contribution to institutional efficiency—the obligation to be loyal to a trust, to act promptly, to concentrate his energy, to do the things given him to do no less well than he may. This paper cannot properly be closed without an attempt to urge upon the subordinate a sense of his responsibility in the game. He must be a dependable unit if he is to continue to play his part, but it is important to all concerned—himself included—that he be something more than just dependable. No one can honestly separate his own success and advancement from the success and advancement of his employer, but it is easy and proper for an institution determined upon progress to separate itself from a slipshod, inattentive, indifferent, and half-hearted employee. Learn initiative, develop a capacity for independent action, and show a willingness and readiness to put your shoulder to the wheel for the benefit of all. Efficiency is not attained by accident. It is the offspring of imagination, interest, intelligence, industry, discipline, enthusiasm, and determination. The three greatest of these are the first two and the last, if we assume intelligence. The others will follow. As for discipline, no individual can afford to shy at it and no institution, however democratic, can neglect it. Neither the individual nor the group can succeed without it. The word is popularly and erroneously supposed to mean the sacrifice of private judgment—of a conceived right to do as one pleases. What it really means is a full-grown will-power (one of man's greatest, but most neglected, possessions), self-control, and a fitness to live and work

among one's kind, and it constitutes the basis of that team-work which accomplishes big results, in that it makes it possible for each individual to contribute his full quota to the general prosperity. There should be no inertia in a subordinate requiring the prompting of his chief. This immediate superior should be convinced by action that assigned duties or tasks will be performed efficiently and expeditiously; that he may look with confidence for results; and that, once an order is given, he may dismiss the matter from his mind in the interest of other constantly appearing, pressing problems, in the knowledge that the matters so intrusted will in due time be placed before him in completed form.

The administrative head of a large establishment is too busy to have to bear in mind or keep before him the hundred-and-one matters under his jurisdiction connected with its operation. He has a right to expect his subordinates to exhibit a sense of responsibility, and to relieve him of such a necessity, once he has given an order or expressed a desire and explained his purpose in either. Remember that the subordinate's area of discretion is his right to do right as he pleases—his right to pursue his own methods so long as he is loyal to the aim of his superior and gives the results desired—"delivers the goods," according to specification and in expeditious fashion.

In conclusion it may be said that one's bearing in relation to others and the attitude one assumes toward a given task will go far to determine success or failure. A determination to do the best one can will open up unexpected vistas of interest and inject an enthusiasm into a seemingly dull and prosaic field of duty.

"The very fact that one is exercising his own ingenuity, searching for new avenues of usefulness, and giving some service from his powers to originate beyond the strict letter of the . . . (requirements), gives birth to a subtly gratifying sense of contribution to that part of the public weal in which one's lot is cast; to a feeling of partnership—even proprietorship—in the increasing efficiency of the . . . (establishment)."

"If to do were as easy as to know what were good to do, chapels had been churches, and poor men's cottages princes' palaces." These are words which Shakespeare put into Portia's speech. But I am of opinion with Thomas C. Galbreath that "to know what 'were good to do' is not easy; it is far more difficult than doing it after one knows," and I have, therefore, been encouraged to present my observations.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

REPORT OF THE BUREAU OF STANDARDS IN THE CASE OF ECONOMY FUSE AND MFG. CO. VS. UNDERWRITERS' LABORATORIES, INC., CONCERNING THE FIRE AND ACCIDENT HAZARD OF THE ECONOMY REFILLABLE FUSE.[1]

[ABSTRACT]

THIS report represents the results of the investigation carried out by the Bureau of Standards acting as referee on the joint request of the Economy Fuse and Mfg. Co. and Underwriters' Laboratories, Inc., on the question of the relative fire and accident hazard of Economy Refillable fuses and fuses at present listed as standard by Underwriters' Laboratories, Inc.

The joint appeal was made to the Bureau under date of May 17, 1915, and the question submitted for decision was as follows:

"Has it been shown that the use of the fuses manufactured by the Economy Fuse and Mfg. Co. results in no greater fire or accident hazard than the use of other cartridge enclosed fuses at present listed as standard by Underwriters' Laboratories, Inc.?"

The evidence on which the finding of the Bureau was based includes a large number of tests of fuses under widely different conditions as well as inspections of numerous fuse installations in practice, personal interviews with many fuse users, evidence and arguments submitted by the Economy Fuse and Mfg. Co. and Underwriters' Laboratories both at a public hearing and by correspondence, and evidence and arguments submitted by a number of manufacturers of fuses at present listed as standard by Underwriters' Laboratories.

During the course of the Bureau's investigations it was shown that the Economy fuse when new and properly filled or refilled operates satisfactorily under the most common working conditions of overload and moderate short circuit, and it was also shown that this fuse possesses some marked advantages over the approved fuses with which it was compared. The Economy fuse

* Communicated by the Director.

[1] Technologic Paper No. 74.

is, however, distinctly inferior to most of the approved fuses under severe short circuit conditions. It has not yet been established that it will not introduce hazards peculiar to refillable fuses owing to deterioration from repeated blowing of the fuse elements in the same casing and possibly from long-continued subjection of the fuse to the working current. The approval of the present type of Economy fuse for unrestricted use would therefore result in a lowering of the standard of fuse performance under severe test conditions and might introduce hazards in actual use the importance of which it is difficult to estimate at this time.

The experience with the present type of Economy fuse is not yet sufficient to determine whether the total hazard is greater or less than it is with approved fuses as they are actually used in practice. The investigation, therefore, leads to the following finding:

" It has not been shown that the use of the fuses manufactured by the Economy Fuse and Mfg. Co. will result in no greater fire or accident hazard than the use of enclosed cartridge fuses at present listed as standard by the Underwriters' Laboratories, Inc.

" On the other hand, the evidence in the case does not show that the use of Economy fuses has on the whole resulted in any greater fire or accident hazard than is involved in the use of standard enclosed cartridge fuses.

" In comparison with fuses listed as standard by Underwriters' Laboratories, the fuses at present manufactured by the Economy Fuse and Mfg. Co. have been shown to possess certain features which tend to increase the hazards involved in the use of fuses, and other features which tend to reduce such hazard. The relative importance of these features can be determined only by extended experience under working conditions.

" It is therefore recommended that Economy fuses be not approved at present for general use on the same basis as fuses at present listed as standard by Underwriters' Laboratories, Inc., but that a continuation and extension of their use be permitted by municipal and underwriters' inspection departments under conditions where their performance can be observed by each inspection department until sufficient experience regarding their performance under service conditions can be obtained to justify an unqualified approval or refusal to approve."

The evidence on which the finding has been reached is summarized and discussed in the report. The report contains about 350 printed pages including numerous tables and 110 oscillographic records, showing the performance of both Economy and approved fuses under various short circuit conditions.

THE CONSTITUTION AND MICROSTRUCTURE OF PORCELAIN.*

By A. A. Klein.

[ABSTRACT]

A PETROGRAPHIC microscopical study of porcelains prepared in the laboratory of the Bureau of Standards and of commercial porcelain, as well as of various combinations of the raw materials which enter into porcelain, has led to results which are interesting and important ~~both~~ scientifically and technically.

Bodies and mixtures of the following types were examined: kaolin, feldspar-kaolin, feldspar-quartz and feldspar-clay-quartz. These were burned to various known temperatures. The commercial bodies investigated represented the practices of the following countries: United States, England, Germany, France, Austria, Denmark and Japan. The end in view was to obtain data concerning the change involved by burning porcelain at various temperatures, and it was found possible to correlate to a certain degree the constitution and microstructure with the burning temperature of bodies whose composition lay within the limits of whiteware and hard fired porcelains.

The result of this investigation leads to the following conclusions: Kaolin appears homogeneous microscopically when heated up to 1200°. At about this temperature a trace of dissociation occurs. As the temperature is raised above 1200° the dissociation increases very slowly at first, then at an increasing rate, until at 1400° it seems to be complete. The products of dissociation are silica and aluminum silicate. The latter compound has been identified as an amorphous phase of sillimanite from the following facts: It shows no crystalline form, has an index of refraction above 1.60, and by heating at a higher temperature (about 1450°) it inverts to minute needle crystallites corresponding to sillimanite in all determinable optical properties.

* Technologic Paper No. 80.

Up to 1340°, in mixtures of quartz and feldspar, the quartz dissolves to only a small extent in the feldspar glass. At 1460° the quartz is practically completely dissolved in specimens having as high a quartz content as 50 per cent. quartz to 50 per cent. feldspar.

At 1340° in specimens containing kaolin and feldspar, the kaolin dissociates entirely. The amount of crystallized and amorphous sillimanite increases with an increased content of kaolin at least to a concentration of 50 per cent. kaolin to 50 per cent. feldspar.

At 1460° apparently 10 per cent. kaolin is entirely soluble in the feldspar glass. With higher concentrations of kaolin the amount of crystallized sillimanite increases. The needle crystals are well developed and comparatively large.

At 1310° in quartz-clay feldspar bodies, the feldspar is present as a glass; the clay shows almost complete dissociation with the formation of amorphous sillimanite mainly and but little crystallized sillimanite, while the quartz is undissolved and the grains may still be of considerable size, up to .2 mm. or more, depending upon the fineness of grinding.

By burning these bodies at 1380°–1400°, the feldspar glass dissolves considerable quartz, there being only a comparatively small amount of quartz remaining. The quartz grains are much rounded and etched, and they seldom show a length over .06 mm. The clay is dissociated with the formation of crystallized sillimanite, although an extremely small amount of amorphous sillimanite may be present.

The changes involved by burning commercial bodies are identical with those of laboratory-prepared bodies. Commercial ware ranges from a low-burned porous whiteware in which, except for the dehydration of the clay, only the feldspar is changed, to very high-fired porcelain which consists of glass, sillimanite crystallites and more or less of residual quartz. The quartz grains observed in the whiteware and in the low-fired vitreous ware are large and angular, showing a size of .2 mm. or more, whereas in the hard porcelains, due to solution, the quartz grains are rounded and etched, and seldom exceed .05 mm. in length.

The constitution and the microstructure of porcelain depend upon the temperature of burning, and change as this temperature changes. This has served as a basis for the estimation of the

probable burning temperatures of the commercial bodies, which was accomplished with success, the error involved being within 25 degrees. It appears that the time of burning factor is by no means as important as that of the burning temperature in determining the constitution and microstructure of the ware.

No cristobalite or tridymite has been definitely observed in any of the laboratory or commercial bodies examined. It appears that the quartz dissolves in the feldspar glass more readily than it inverts to the other modifications of silica.

In conclusion, it may be stated that the petrographic microscopic study of porcelain led to interesting and, it is to be hoped, important technical results. It has placed the chemical and physical processes involved in the formation of porcelain on a more quantitative thermal basis. Furthermore, it has offered a means of estimating the burning temperature of a ware from the examination of a fragment much too small in size to be satisfactory for even a chemical analysis.

THE FAILURE OF BRASS.—2. THE EFFECT OF CORROSION ON THE DUCTILITY AND STRENGTH OF BRASS.*

By Paul D. Merica.

[ABSTRACT]

Results of investigation made on a homogeneous, alpha brass, have shown that the electrolytic solution potential of this material is increased by the application of a tensile stress. This increase, as measured, amounts to approximately 0.1 millivolts for 10,000 lbs./sq. in. of stress.

Using this fact as a basis, an explanation can be given of the decrease of strength and ductility of brasses when corroded while under stress. Over a roughened surface of a bar under tensile stress, this stress will vary in value, being greatest at the bottom of furrows and depressions and least, almost zero indeed, at the tops of the ridges. The EMF will therefore, other things being equal, be greater; *i. e.*, more electropositive, at the bottom of these furrows than elsewhere; corrosion will set in here most rapidly forming a crack, which will grow narrower and sharper, its rate of growth being greater, the sharper it is. In time the cross-

*Technologic Paper No. 83. Complete copies of the paper may be obtained by application to the Bureau of Standards, Washington, D. C.

section of such a bar is so reduced by these cracks, that fracture occurs, the brass failing apparently at a stress value less than the ultimate strength, and exhibiting only light elongation (ductility).

This explanation is borne out by the examination of a number of brass failures, which have occurred under such conditions.

THE FAILURE OF BRASS.—3. INITIAL STRESS PRODUCED BY THE "BURNING-IN" OF MANGANESE BRONZE.*

By Paul D. Merica and C. P. Karr.

[ABSTRACT]

In connection with the failure by cracking of a number of manganese bronze valve castings in the Catskill Aqueduct, at or near areas repaired by "burning-in," an investigation has been made of the initial stress produced in a manganese bronze double bar casting, by the burning-in of a constrained portion. The stresses measured were in each case about 8000 to 10,000 lbs. / sq. in.; *i.e.*, the true elastic limit of the material, and the material within the burned-in area was of course in tension. The micro-structure of the portion, adjacent to the burned-in metal was not altered; the burned-in metal was in all cases of finer grain than that of the casting.

The conclusion is reached that, although distortion of a burned-in casting may partially relieve the initial stresses set up by this operation, such castings will in all probability, generally, contain local stresses of dangerous magnitude; *i.e.*, near the elastic limit of the material. Castings, repaired in this manner, should then, either be thoroughly preheated or subsequently annealed in order to eliminate these stresses, which are responsible for later failure by cracking, as described above.

THE DETERMINATION OF THE DEGREE OF UNIFORMITY OF BARS FOR MAGNETIC STANDARDS.*

By Raymond L. Sanford.

[ABSTRACT]

Magnetic standard bars are used for the calibration of permeameters and the comparison of methods of magnetic testing with a standard method. One requisite of a magnetic standard

* Technologic Paper No. 84. A copy of this paper may be obtained by application to the Bureau of Standards, Washington, D. C.

* Scientific Paper No. 295.

bar is that it shall be magnetically uniform along its length. If this condition is not met, errors may arise which cannot be calculated or eliminated from the measurements, and which may be of considerable magnitude.

The degree of magnetic uniformity of a bar may be determined from observations of the distribution of magnetic leakage along the length of a specimen when it is magnetized between the poles of a suitable electromagnet. The degree of uniformity is indicated by values of the rate of change of leakage along the length of the bar. Deviations of these values from a constant indicate the presence of non-uniformities. An increase in the value indicates a magnetically hard spot while a decrease indicates a soft spot. The degree of uniformity can be indicated by means of a curve plotted between values of the rate of change of leakage and displacement along the length of the bar. This curve is called the uniformity curve and for a uniform bar is a straight line parallel to the axis of displacement.

Errors in magnetic measurements due to non-uniformities depend upon the induction, the nature, location, magnitude and extent of the non-uniformities and upon the type of apparatus. For a given accuracy, no ordinate of the uniformity curve must deviate from the mean by more than a given amount.

This method may be applied to the examination of magnetic materials for mechanical inhomogeneities and the detection of flaws.

THERMOELECTRIC MEASUREMENT OF THE CRITICAL RANGES OF PURE IRON.*

By George K. Burgess and H. Scott.

[ABSTRACT]

The methods hitherto employed for the determination of the thermoelectric properties of conducting materials possess the characteristic, which is particularly disadvantageous in the case of a substance such as iron, which has two critical ranges, in requiring a length of the material in question to have a temperature distribution from the maximum to the lowest. There may then be ambiguity or superposition of thermoelectric effects.

* Scientific Paper No. 296.

Using a length of pure iron wire (Fe = 99.968) of some 7 cm. length and 0.5 cm. diameter joined between the hot junctions of two Le Chatelier thermocouples within a furnace 60 cm. long, several series of accurate observations in vacuo of the thermoelectric power of the couple Iron-Platinum have been taken, at 2° intervals, over the temperature range 0 to 1000° C.

The critical point A_3 is marked by a discontinuity of considerable magnitude in the thermoelectric power vs. temperature curve at about 915° C. on heating and 900° C. on cooling. At A_2 there is a change in shape of the curve. The thermal effect at A_2 is superimposed upon the thermoelectric and manifests itself as a slight protuberance or dent at 768°.

The following table gives the thermoelectric power (dE/dt) Peltier effect (TdE/dt) and Thomson effect (d^2E/dt^2) for iron-platinum from 0 to 1000° C.:

Thermoelectric Power of Iron Against Platinum.

Temperature Centigrade t	Microvolts per degree dE/dt		Peltier Effect TdE/dt		Thomson Effect d^2E/dt^2	
0	19.5		5320		−0.010	
100	18.1		6750		−.027	
200	15.4		7280		−.035	
300	11.7		6700		−.033	
400	9.5		6390		−.010	
500	9.1		7030		+.009	
600	10.8		9430		+.026	
700	14.3		13910		+.036	
780	18.1		18980		+.045	
800	18.4		19740		+.014	
880	19.4		22350		+.010	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
900	19.7	17.5	23100	20510	.000	−.400
910	19.4	10.8	22940	12770	−.050	−.040
920	16.6	10.9	19800	13000	−.575	+.010
930	11.4	11.1	13710	13350	−.023	+.017
1000	12.6		16030		+.017	

These thermoelectric observations give further evidence of the distinct character of the critical points A_2 and A_3 delimiting the regions of alpha, beta, and gamma iron.

LIQUID MEASURING PUMPS.*

By F. J. Schlink.

[ABSTRACT]

The importance of the measuring pump is principally due to the large quantities of gasoline sold as fuel for motor cars, by far the greater part of this commodity being sold through the various forms of measuring pumps. About 27 firms are engaged in the manufacture of the various measuring pumps and liquid dispensing systems.

The principal advantages of this type of apparatus lie in its convenience in delivering gasoline directly to the tank of the automobile, with a minimum of evaporation, spillage and fire hazard.

The first and ~~most~~ common type of measuring pump is the piston pump, which is in principle the usual plunger pump with stops which act to define accurately the limits of the piston stroke, and consequently the volume generated by the piston on each cycle. Both single-acting and double-acting piston pumps are used for measuring purposes. In addition to the pumps with reciprocating pistons, pumps with rotating pistons are used, the application of these at the present time being more familiar in the so-called molasses pumps, which are especially adapted to the handling of viscous liquids.

Most reciprocating and rotary piston pumps are provided with a counter or tally to indicate the number of strokes or cycles which have been completed. Such counters should be so designed and located that they will operate correctly, indicate unmistakably, be actuated only very near the conclusion of the stroke or cycle, and be plainly visible to and readable by both merchant and customer.

In a second type of apparatus, the measurement is performed by passing the liquid through a meter, commonly of the nutating-piston type, the discharge of liquid through the meter being produced either by displacement of the oil over water, by pneumatic pressure, or by mechanical pumping. With the type of meter now used, it is important that the rate of flow through the meter be maintained as nearly constant as possible, and the liquid stream must be kept free from solid particles and sediment, or the meter regularly and carefully cleaned.

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* Technologic Paper No. 81. Read at the Eleventh Annual Conference on Weights and Measures of the United States, May 23, 1916.

A third type of measuring system is founded upon the principle of overfilling a measuring chamber, supplying liquid until an excess is present over the nominal delivery, and then removing the excess by abstraction to a definite level. The liquid may be supplied to the measuring chamber by air pressure, by evacuating the chamber with a vacuum pump, or by direct mechanical pumping from the supply tank. The abstraction of the excess may be performed either by gravity through an overflow pipe, or by siphoning, the height of the liquid remaining being determined by the vertical height of the face of the orifice of such pipes above the bottom of the measuring chamber. In a modification of this type, the measurement is obtained by direct reading of the height of the liquid column on a graduated scale, at the beginning and end of the withdrawal of the liquid from a tank or cylinder. The cross-sectional area of such tanks must be limited in order that the volume value of the scale interval be not excessive.

A portable apparatus is also in use, comprising a small storage tank and a measuring pump, the whole arrangement being adapted for moving to the place of filling most convenient to the purchaser. Such devices favor a higher precision than most stationary tanks in that the suction lift can be kept at a minimum, and the danger of vaporization and leakage below the piston is much reduced.

In the testing and inspection of measuring pumps it is essential to determine whether the installation is free from inward leaks of air and outward leaks of gasoline. Leaks of either kind are fatal to accurate measurement, and any adjustment made before the correction of defects of this kind cannot be expected to be permanently effective. Much trouble of this nature can be prevented by following with scrupulous exactness the instructions of the manufacturers, which are provided to guide the owner in making the installation.

The principal causes of short delivery of pumps of the piston type are leaking of foot valves, and formation of vapor or air space under the piston, resulting from excessive virtual suction lift or leaky piping, or piping containing traps tending toward the periodical retention of vapor. It appears that a total vertical suction lift greater than 7 feet may be excessive with the ordinary commercial (not "blended" or "casing-head") gasolines. "Casing-head" or "blended" gasoline should not be lifted any appreciable vertical distance on the suction side in those types of

pumps in which the piston and cylinder form the measuring element, on account of the vaporization difficulty already mentioned. Special installations, in which the pump is located at or near the level of the supply tank, should be employed for the last-mentioned grades of gasoline.

Another source of error which should be guarded against in design and installation of piston measuring pumps is the inertia of the moving liquid column.

The use of long filling-hoses, and of hoses so arranged that they cannot be readily drained, results in cases of short delivery to individual purchasers; this should be obviated by so relating the length of hose and the height of hose connections that the hose can always be readily drained to a definite level. A measuring pump should not be installed inside a building with the hose connection outside, unless so arranged that the manner of operation of the pump is clearly visible to the purchaser. The writer also questions the advisability of permitting the use of a shut-off cock on the outer or delivery end of the hose, as its use may readily operate to prevent the regular drainage of the hose into the customer's tanks.

It is recommended that the design of piston type measuring pumps should tend toward types which cannot be operated through less than full strokes without that incompleteness of the cycle being clearly indicated to the customer. This certainty of stroke completion is readily obtainable in simple designs, which so far as the writer knows have not yet been offered for use.

In order to prevent the short deliveries consequent upon operating the piston pumps at less than full stroke, they might well carry a clearly legible placard or notice, reading "This Pump to Deliver—Gal. for Each *Full* Stroke."

Pumps which provide for the return of undelivered liquid to the storage tank should be equipped with some manner of device which will prevent this return taking place at the same time that liquid is being delivered to the purchaser, as such diversion of a portion of the customer's purchase constitutes an easy means to fraud.

In testing pumps, the hose should be removed if this is feasible, and the test delivery made from the pipe outlet, unless a suitable can-filling outlet is provided. Test should be made with a standard measure of suitable capacity and of the conical type,

used in combination with a cylindrical graduate reading to cubic inches, or by a measure of special form, similar to that designed by Mr. Theo. Seraphin of Philadelphia, which comprises a zero graduation for the correct discharge, and additional graduations for deliveries in excess and efficiency, so arranged as to cover the normal range found in the field work. Two speeds at least, one faster and one slower than normal operation, should be used in the test in order to determine whether or not the action of the pump is substantially independent of the speed of operation.

It is recommended that piston measuring pumps which have been standing unused for a considerable length of time be operated for one or two strokes to eliminate the first stroke short delivery which often occurs on account of valve leakage, vaporization, thermal contraction, etc.

Proper sealing of the pump by the weights and measures official means not merely the attaching of a sticker or tag to the pump, but the actual sealing by wires and soft metal seals of all accessible portions of the pump upon which adjustments or alterations can be made which will affect the volume of the pump discharge. The manufacturers will be glad to furnish drawings and instructions relative to the points of adjustment on their own makes of pumps. The manufacturers should be required to provide all their pumps with suitable drilled holes or devices to facilitate this sealing by the weights and measures official.

A careful, full and explicit record of the test should be made. The complete paper contains a form well adapted for this purpose, which owing to lack of space cannot be included here.

Results of the tests in the field indicate that pumps in service show a decided tendency toward undermeasurement, this being due to the fact that nearly all of the defects of construction or installation tend to produce errors in this one direction. These include: leaks of air and liquid, retention of liquid by the hose, vapor formation consequent upon excessive suction head, failure to complete the full stroke, and slippage of liquid past valves and piston.

The Bureau will endeavor to maintain a full and up-to-date mailing list of manufacturers of measuring pumps, and will supply these names upon request. Particular inquiries on matters in this field, referred to the Bureau of Standards, will be given careful attention.

NOTES FROM NELA RESEARCH LABORATORY.*

ON PHOTOELECTRIC PHOTOMETRY.

By Jacob Kunz.

In the present field of photoelectric investigations four principal groups may be distinguished. The first group is concerned with the fundamental problem of the relation between the velocity of the electrons emitted and the frequency of light; the second with the relation between the intensity of light and the photoelectric current; the third with the normal and the selective effect; and the last with the influence of gases. The present investigation deals with the second problem. Several physicists have attacked this question with widely disagreeing results. Elster, Geitel and Richtmeyer found a linear relation between the two quantities; Griffith, Lenard and Ives on the other hand found non-linear relations; Ives especially found a large variety of curves. It was the purpose of the present investigation to find out the true relation and an explanation for the discrepancies among the previous results.

The photoelectric cells used were of different types. The largest number investigated were of spherical shape as described in a recent number of the *Physical Review*. The anode was a circle across which there were wound fine platinum wires in order to create an approximately uniform field. The larger part of the sphere was covered with the sensitized alkali metals, sodium, potassium, and rubidium; only a small hole of about 8 mm. diameter was left free for the entrance of the light. The intensity of light was varied by moving the source to and from the cell, or by means of Nicol prisms, or by means of a rotating sector disk. The current was measured by means of a sensitive galvanometer or by means of a large constant resistance and the electrometer, by the accumulated charge or by the drift method.

When the galvanometer was used the light intensities were rather high, and the result was without exception a curve concave toward the light intensity axis, but it was observed that the curve approached a straight line, when the intensity and the hole through which the beam of light entered the photoelectric cell

*Communicated by the Director.

was decreased. With an opening of about 5 mm. practically straight lines were obtained. The same result was also obtained with the other three independent methods. In the majority of cases the highest point was about one or two per cent. above the straight line, a point which will be further investigated. The light intensity varied from 1 to 36. The results are indicated by the following two series of observations. I = intensity of light, i = photoelectric current.

i	I	$\frac{I}{i}$	i	I	$\frac{I}{i}$
9.0	12.8	142	7.15	11.1	155
34.6	48.8	141	15.9	25	157
70.9	101.3	142	28.5	44.5	156
106.5	151.5	142	63.6	100	157
139.6	200	144	98.6	156.2	158
186.6	268	144	128.2	204	159
226.3	326	144	175.7	278	158
251.8	360	144.1	212	331	157
276.7	397	144.3	262.2	400	154

As resistances were used a cadmium sulphate solution in a capillary tube about $\frac{1}{1000}$ normal, a graphite resistance as used by Ives and a photoelectric resistance. The graphite resistance was not very reliable. According to its surface conditions one can obtain, with the same cell and with the same light intensities, curves of widely different character, concave, convex, and irregular. But it is occasionally possible to have the resistance in a very good condition and then straight curves are obtained with the doubtful exception of the highest point.

Other types of cells have been constructed which gave, however, less satisfactory results. In one cell an approximately uniform field was created between two plane parallel electrodes, the lower being made of alkali metal, the upper of silver wire netting. A third parallel electrode was at the same time introduced in order to apply a counter field. Ives himself has claimed to obtain, without giving evidence, a straight line by means of a large spherical field; a cell constructed according to his prescription, gives approximately a straight line, but not so distinctly as the small cells, described above. If light is applied to the cell without a potential difference, then the light interrupted and the field applied, there was found a considerable photoelectric current.

Nela Park, Cleveland, Ohio.
October 9, 1916.

THE EMISSIVE POWER OF TUNGSTEN FOR SHORT WAVE-LENGTHS.

By E. O. Hulbert.

IN this investigation the variations in the emissive power of tungsten have been determined between 3200 A° and 5500 A° for true temperatures, according to Worthing's scale,[1] from 1746° K to 2785° K. Preliminary spectrograms of a tungsten strip through a quartz window at various temperatures showed an appreciable amount of radiation as far as 2900 A°. The light from the tungsten in a glass bulb was studied quantitatively by means of a grating spectograph with a sodium photo-electric cell and electrometer. The relation between the energy incident on the cell and the deflection of the electrometer was found to be a linear one for monochromatic radiation. The transmission of the glass, hot and cold, was determined; the measurements were corrected for this effect and for the finite width of slits.

The change in emissive power with wave-length was determined by measurements on a black body at the melting point of paladium, 1822° K, and on the tungsten at a temperature 2143° K. Conditions were the same in the two sets of measurements except as regards to slit widths. Because of this difference and because of some scattered light which was later noticed in the spectra, the black-body calibration has been used only in determining the relative changes in the emissive power with wave-length. In the table the absolute values given depend on the value .470 for wave-length 4677 A° at 2143° K (from unpublished measurements by Worthing). The emissive power is seen to increase with decrease in wave-length.

TABLE I.
True Temperature 2143° K
$C_2 = 14460$ deg. xμ

Wave-length	Emissive Power of Tungsten
3478 A°	.470
3717	.487
3956	.484
4196	.495
4435	.466
4677	.470
4916	.460
5158	.453
5400	.447
5641	.436

[1] A. G. Worthing, JOUR. OF FRANK. INST., 181, p. 417, 1916. *Phys. Rev.*, 7, p. 497, 1916.

The change in the emissive power with temperature was determined by drawing the "isochromes," *i. e.* the curves for a constant wave-length showing the relation between the logarithm of the energy emitted and the reciprocal of the temperature. The isochromes were found to be straight lines within the error of experiment. Calculations based on the determinations of the slopes of these lines showed that the emissive power increased as the temperature decreased for all the wave-lengths under investigation. The data further indicated that the rate of increase of emissive power with decrease of temperature became greater as the wave-length became shorter.

Nela Park, Cleveland, Ohio,
October 3, 1916.

Fixing a Photographic Plate Before Development. ANON. (*Revue Generale des Sciences,* vol. 27, Nos. 15–16, August 15–30, 1916.)—At first sight it may appear absurd to think of fixing a photographic plate before the latent image has been developed, because fixing consists in dissolving the reduced bromide of silver. When an exposed sensitive plate is treated with hyposulphite of soda the opaline coating becomes completely transparent; not the least trace of an image is discernible, and the gelatine appears to contain nothing that can be disclosed by photochemical action. Nevertheless, paradoxical as it appears, this method is not only theoretically possible but has also several practical applications. If it were not limited to plates greatly over-exposed (six to eight times normal exposure), it would solve, better than any other process, the problem of development in open light.

The plate, protected from actinic light, is first immersed in a 2 per cent. solution of hyposulphite of soda. This bath dissolves the bromide of silver much more slowly than the usual fixing bath of 20 to 25 per cent. strength, but the latter has the disadvantage of destroying the delicate half-tones. Dissolution requires about 30 to 40 minutes, according to the thickness and hardness of the gelatine. The plate can then be developed in full daylight. If desired, the plate may be washed and dried and laid aside for future development. The image is disclosed by *physical development*, that is to say, by bringing a reducing agent and a soluble salt of silver in contact with the exposed film. The developer will contain, for instance, pyrogallol and nitrate of silver. The pyrogallol decomposes the nitrate of silver, and the silver so precipitated is deposited upon those points of the sensitive coating which have been exposed to the light and in quantities proportional to the exposure. The exposed points constitute in fact so many centres of attraction for the deposit of silver which are progressively reinforced.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE MEASUREMENT OF THE ABSOLUTE VISCOSITY OF VERY VISCOUS MEDIA.[1]

By S. E. Sheppard.

[ABSTRACT]

WHILE the fall of a denser body through a liquid is frequently used by industrial chemists as a measure of viscosity, the values obtained are usually taken as *fixed empirical standards*, neither absolute nor relative viscosity coefficients being derived. It is pointed out that Stokes' equation for falling bodies enables these to be determined from readily measured quantities, the equation being expressed in the form:

$$K = 2/9\, R^2 (S - S')g/U.$$

where K = coefficient of viscosity.
R = radius of sphere.
S = density of sphere.
S' = density of liquid.
U = terminal velocity of fall.

An important condition is the ratio of the diameter of the vessel to that of the sphere. This ratio, say γ, should be very large if the equation is to give correct results. In the paper of which this is an abstract details are given of an experimental investigation dealing particularly with this factor. Steel ball bearings of ½ in., ¼ in., and ⅛ in., true to $\mp .02\%$ were used, falling in a very viscous nitrocellulose solution. It is found that if T be the time of fall over a fixed interval L in the steady state when $U_{\text{lim.}} = L/T$, when the values of T diminish steadily as the ratio γ increases, approaching a constant limit for very great values of γ. An empirical equation is obtained for the function $T = f(\gamma)$ of the form

$$T = T_K + C/(\gamma - 1)^2$$

where T_K is the true time of fall for $\gamma = \infty$ and C is a constant for the experimental conditions. The correspondence of the calcu-

*Communicated by the Director.

[1] Communication No. 40 from the Research Laboratory of the Eastman Kodak Company.

lated values with the experimental data is exhibited in curves. The expression is compared with one obtained from theoretical considerations by R. Ladenburg (Ann. Phys. 23, 287, 447, 1907) which gives somewhat lower values for the viscosity, but is only valid on one side of the range. The expressions for Stokes' law in the case of cylindrical vessels, corrected for the influence of the wall, are:

$$K = \frac{2/9\,R^2}{L}\,(S-S')\,\frac{T}{1+2.4/\gamma} \qquad \text{(Ladenburg)}$$

$$K = \frac{2/9\,R^2}{L}\,(S-S')\,T - C/(\gamma-1)^2 \qquad \text{(Sheppard)}$$

THE ELECTROLYTIC DETERMINATION OF SILVER FROM CYANIDE SOLUTIONS.[1]

By A. S. McDaniel and L. Schneider.

[ABSTRACT]

THE electrolytic determination of silver from cyanide solutions as described in manuals on electro-analysis is subject to relatively large errors and therefore cannot be used in its present form for the assay of certain photographic raw materials and products where a good degree of accuracy is of prime importance. If it were not for these errors the method would be specially convenient for this class of materials.

The method has been carefully standardized and the different sources of error identified and their magnitude determined. The plus errors are due mainly to inclusions produced by colloids. The minus errors are due to cathodic corrosion and losses in washing. It has been shown that under certain conditions, especially with certain classes of material, the plus and minus errors almost exactly balance, while under other conditions either the plus or the minus errors predominate. These facts account for the widely varying results obtained by the method in the hands of different analysts. A procedure is given for overcoming these errors. This results in a highly satisfactory method both as to accuracy and speed. The accuracy obtainable suggests that with certain further refinements the atomic weight ratios of the halogens and of nitrogen to silver could be determined by the analysis instead of the synthesis of the appropriate silver salts.

[1] Communication No. 19 from the Research Laboratory of the Eastman Kodak Company.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, October 18, 1916.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 18, 1916.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 25.

The following communication from the Board of Managers was presented:

"The Board of Managers at its regular meeting held September 13, 1916, confirmed the action of the Committee on Stocks and Finance in disposing of the property 1911 N. 18th Street, representing a portion of the investment of the Bloomfield H. Moore Memorial Library fund, and requests the Institute to ratify and approve the action by passing the following resolution: 'At a regular meeting of The Franklin Institute held October 18, 1916, a quorum being present and voting, it was unanimously, *Resolved*, That the sale of premises 1911 North 18th Street, heretofore made to Gertrude Mieterer for the sum of $3000, be ratified and confirmed, and that the action of the President and Secretary in executing a deed for the said premises unto the said Gertrude Mieterer, be approved.'" The resolution was passed unanimously.

Mr. Charles E. Bonine, Chairman of the Committee on Science and the Arts, reported the condition of the work of the committee. The Chairman called attention to the appointment of a National Research Council by the National Academy of Sciences on the request of the President of the United States, and stated that the purpose of the Council was to bring about further co-operation between existing governmental, educational, industrial, and other research organizations, with the object of encouraging the investigation of natural phenomena and the increased use of scientific method in strengthening national defense. He requested the Institute to authorize the appointment by the President of the Institute of a special committee to aid the Council in any line of work it may conduct and in which it might desire the co-operation of the Institute, whereupon the following resolution was adopted:

Resolved, That the President of the Institute be authorized to appoint a Committee of the Institute to co-operate with a similar Committee of the National Academy of Sciences for the further organization and encouragement of scientific research in the United States.

Mr. Charles E. Bonine, Chairman of the Committee on Science and the Arts, then introduced Mr. Carl E. Akeley of New York City, to whom had been awarded the John Scott Legacy Medal and Premium by the City of Philadelphia, on the recommendation of The Franklin Institute, for his Cement Gun. This apparatus is used for applying cement mortar and stucco,

the material being applied in the form of a spray upon the object to be coated.

The President presented the medal and accompanying certificate to Mr. Akeley, who returned his thanks for the honor conferred upon him.

Mr. Bonine was again recognized, and introduced Mr. John Van Nostrand Dorr of New York City, to whom had been awarded the John Scott Legacy Medal and Premium by the City of Philadelphia, on the recommendation of The Franklin Institute, for his Hydro-Metallurgical Apparatus, namely, the Dorr Thickener, the Dorr Agitator, and the Dorr Classifier, which have lately been used extensively in the cyanide industry.

The President presented the medal and accompanying certificate to Mr. Dorr, who expressed his thanks for the recognition of his inventions.

After the transaction of the above business, a joint meeting was held with the Philadelphia Section of the American Institute of Electrical Engineers, Mr. H. P. Liversidge presiding.

Dr. Charles P. Steinmetz, Chief Consulting Engineer, General Electric Company, Schenectady, N. Y., addressed the meeting on "Scientific Research in Relation to the Industries." The speaker stated that as engineering is an applied science, the engineering industries naturally depend for their success upon the use of correct scientific principles and the application of newly discovered scientific facts. Since established research institutions were not able to furnish all the information desired for use in the industries, industrial establishments have recently gone into scientific research with vastly extended facilities, with the result that of late the largest number of scientific advances have been made in industrial research laboratories. In Germany it was first realized that the establishment of the industrial research laboratory was one of the most profitable investments which could be made by the large industries, but in the last few years American corporations have also fully awakened to a realization of this fact, and the research laboratories established in this country by industrial corporations are doing scientific work of the highest order in chemistry, physics and mechanics.

Numerous illustrations of research methods, and of the value of the results of industrial research were given.

After a brief discussion a unanimous vote of thanks was tendered the speaker and the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, October 4, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 4, 1916.

DR. GEORGE A. HOADLEY *in the Chair.*

The following reports were presented for first reading:

No. 2638.—Continuous Automatic Centrifugal.

No. 2674.—Rubber Hysteresis Tester. This latter report was made advisory and adopted.

The following reports were presented for final action:

No. 2675.—Sharples Super-centrifuge. Action deferred.

No. 2676.—Composite Low Expansion Electric Lamp Leading-in Wires. Elliott Cresson Medal to Dr. Byron E. Eldred, of New York, N. Y., adopted.

R. B. OWENS,
Secretary.

SECTIONS.

Mechanical and Engineering Section.—A meeting of the Section was held in the Hall of The Institute on Thursday, October 5, 1916, at 8 P.M.

Mr. Charles Day occupied the Chair.

W. J. Humphreys, C.E., Ph.D., Professor of Meteorological Physics, U. S. Weather Bureau, Washington, D. C., delivered a lecture entitled, "The Atmosphere and Aviation." Dr. Humphreys explained the relation of the circulation of the atmosphere to gravity, temperature contrast and earth rotation, and gave brief accounts of trade winds, monsoon winds, cyclones, anti-cyclones, etc.

A practical method was shown for estimating the approximate direction and velocity of the wind, which may be expected at flying levels under any condition of the weather.

Those phenomena of the atmosphere which the aviator knows as "air pockets" or "holes in the air" were also discussed.

Colonel George O. Squier, Ph.D., Aviation Section, U. S. Army, late Military Attache, American Embassy, London, England, War Department, Washington, D. C., delivered a lecture entitled, "Efficient Military Air Service." Colonel Squier gave a very brief outline of the tentative plans thus far developed for producing the necessary matériel and the training of the personnel of the Army Air Service.

After an interesting discussion by Mr. Frederick W. Barker, President of the Aeronautical Society of America, and other gentlemen, a vote of thanks was extended to Dr. Humphreys and Colonel Squier.

Adjourned.

T. R. PARRISH,
Acting Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of The Institute on Thursday evening, October 12, at 8 o'clock, with Dr. George A. Hoadley in the Chair. The minutes of the previous meeting were read and approved.

Louis Vessot King, A.M., ScD., F.R.S.C., Associate Professor of Physics in McGill University, Montreal, Canada, delivered a lecture "On the Acoustic Efficiency of Fog-signal Machinery." The various forms of fog-signal machinery, and the researches conducted with them, were reviewed in historical order. A description was given of the extensive research conducted by Dr. King at Father Point, Quebec, in September, 1913, in which a Northey "diaphone" or siren served as the source of sound, and a Webster "phonometer" served for the measurement of the intensity of the sound at distances as great as 8 miles from its origin. The various conditions which influenced the efficiency of the diaphone were discussed. The lecture was

illustrated with lantern slides, and with the apparatus used in the research.

After a discussion of the paper, a vote of thanks was extended to Dr. King, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, October 11, 1916.*)

RESIDENT.

Mr. Edward L. Clark, Engineer, Commercial Truck Company of America, 27th and Brown Sts., Philadelphia, Pa.
Dr. Thomas E. Eldridge, Physician, 1811 North Logan Square, Philadelphia, Pa.
Mr. Robert E. Glendinning, Banker, 8862 North 32nd St., Philadelphia, Pa.
Mr. C. Stuart Patterson, Banker, 1000 Walnut St., Philadelphia, Pa.
Dr. Max J. Stern, Physician, 711 North Franklin St., Philadelphia, Pa.
Mr. Robert L. Wood, Civil Engineer, Cruse-Kemper Co., Ambler, Pa.

NON-RESIDENT.

Mr. James G. Detwiler, Chemist, The Texas Company, Port Arthur, Texas.
Mr. Armin Elmendorf, Instructor in Mechanics, University of Wisconsin, and for mail, 311 North Murray St., Madison, Wis.
Mr. W. E. Fletcher, Chemical Director, Atlas Powder Company, Wilmington, Del.
Dr. Frederick W. Getman, Chemist, Hillside Laboratory, Stamford, Connecticut.
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NECROLOGY.

Mr. Mathias Pfatischer was born in Bavaria on September 4, 1858, and died at Roselle, N. J., September 10, 1916. He came to the United States in 1882, and for twenty-seven years was Consulting Engineer for the Electro-Dynamic Company, at Bayonne, N. J.

Mr. Pfatischer devised an electric stearing gear for battleships, and designed and installed the electrical equipment on the steamships St. Louis and St. Paul, including the ship's telegraph and other novel features. Among his most important inventions is the Inter-pole Variable-Speed Motor, for which he was awarded the John Scott Medal by the City of Philadelphia in 1908, on the recommendation of The Franklin Institute.

Mr. Pfatischer was a member of the leading electrical societies of this country. He became a member of The Franklin Institute in 1889.

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CURRENT TOPICS.

Origin of the Open-hearth Process. H. H. Campbell. (*The Iron Age*, vol. 9, No. 9, August 31, 1916.)—It was in 1857 that Siemens invented the regenerative furnace, but not until 1861 did he take out a patent for what we now know as the open-hearth; and even then he did not see that a new problem had arisen and that his furnace had almost miraculously appeared just when it was needed, for the Bessemer process had just come into use and large quantities of steel scrap were being produced. Numerous attempts were made to "pile" and weld this scrap, just as always has been done with wrought iron, and schemes of this kind were quite common even in the early eighties; but the welding of Bessemer scrap at that time was out of the question, because practically all the output was rail steel, while a large proportion was too large to be made into any ordinary "bundle."

For a long time after the regenerative furnace had been in operation for heating purposes it was not realized that steel scrap could be melted on an open hearth, and large piles of crop ends and defective blooms accumulated without any practicable method in sight for their utilization. But in 1864 two brothers, named Martin, operated a furnace at Sireuil, in France, and worked out the method, which is so familiar to us to-day, of melting pig iron and scrap together. They obtained patents a year later, and for a long time it was the general custom to speak of the Siemens-Martin or, more briefly, the S. M. process; but to-day we commonly refer to it as the open-hearth. These patents for many years were the subject of litigation in this country, and it was not until after 1880 that the decision was given against the patentees. Pierre Martin died at an advanced age, in an obscure French village where for many years he had lived in poverty. His last days were made comfortable by money raised by public subscription in Europe.

Self-luminous Paint. W. S. Andrews. (*General Electric Review*, vol. xix, No. 9, September, 1916.)—Soon after the discovery of radium by the Curies, in 1898, certain phosphorescent mineral compounds were found to be so sensitive to the radio-activity of this element that they show luminescence when only brought near it, actual contact being unnecessary. A fine quality of zinc sulphide known as Sidot's blende proved to be the most responsive. A next obvious step was to mix a very minute amount of radium salt with finely powdered zinc sulphide, combined with a suitable adhesive so that it might be used as a self-luminous paint. For a long time looked upon only as an interesting scientific curiosity, it has in recent years been applied in various useful ways to make small

objects, such as the hands of timepieces, electric switch buttons, etc., constantly visible in the dark.

This radio-active, self-luminous paint must not be confounded with an article that has been on the market for many years under the name of "Balmain's luminous paint," which was invented by Professor Balmain, of the London University, about the year 1875. The base of the Balmain paint is a special preparation of phosphorescent calcium sulphide, and it requires the excitation of a strong light to make it shine. It absorbs the luminous radiation, and thus emits it again as a soft, phosphorescent glow which gradually fades away, so that in the course of a few hours it ceases to be visible until again excited by phosphorescence. The self-luminous, radio-active paint differs entirely from the above in containing within itself its own exciting power, so that it continues to shine indefinitely, even when kept in perpetual darkness. There is, however, a practical limit to the life of the radium salt and zinc sulphide mixture, but there is no difficulty in meeting the guarantee required by the United States Government for army and navy purposes that it shall maintain undiminished luminosity for two years.

It is well known that the phenomenon of radio-activity is not confined to radium. A product of thorium, known as radio-thorium, is intensely radio-active, but it has a much shorter life than radium. Meso-thorium, from which radio-thorium is evolved, is a by-product of the incandescent gas mantle industry, and, on account of its relative cheapness as compared with radium, it is now being used extensively, either by itself or combined with radium, in the production of self-luminous paints. The relative merits of radio-thorium paint and that energized entirely by radium are unsettled, but both compounds will probably find their appropriate applications.

Problems of the Submarine. ANON. (*The Times* (London) *Engineering Supplement*. Vol. 12, No. 502, August 25, 1916.)—A difficulty in the development of the submarine is in the limitations of suitable machinery for propulsion. For surface speeds up to 18 or 20 knots, it is impossible to use Diesel engines, but unfortunately these engines cannot be constructed to give large powers per cylinder with safety. One cylinder will develop 100 horse-power quite easily and even as much as 150, but beyond the latter value little has been done. Accordingly, to obtain a reasonably large power, a great number of cylinders is required, but here again, in order not to complicate arrangements unduly, not more than twelve cylinders are usually fitted to one shaft. With a three-shaft arrangement, therefore, 5,500 horse-power is the maximum possible. Speeds of 25 knots or more are, however, desirable in submarines if they are to take their place in a squadron, and for these much larger powers are necessary. As a solution to the problem, steam machinery for surface propulsion has been projected developing as much as 15,000 horse-power. With a steam installation, special

arrangements would be necessary to avoid delay in diving, when of course the steam power would not be available. The use of oil fuel would enable the fires to be extinguished by the turning of a cock, while water-tube boilers would hold very little steam, so that the quantity of heat taken down with the boat would be reduced to a minimum. But many drawbacks must be entailed with any steam installation; one of them being that the consumption of oil is three times as great as in an oil engine, so that the radius of action is much reduced, and a decided step would be taken if oil engines could be constructed to give higher powers.

The electric drive still continues to be the only possible one for underwater use. It takes up much space and its weight is very large; about five times the corresponding figure for oil engines. On this account the submerged speeds of submarines have to be low. Further the capacity of the storage batteries limits operations submerged to relatively short runs. An escape of the battery fluid may have serious and even fatal results, and special precautions are taken to guard against such accidents. The Edison battery, though it does not save much in weight, is safer in use than the older type.

The "Lumen" as a Basis of Comparison for Illuminants. L. Gaster. (*The Illuminating Engineer* (London), vol. ix, No. 7, July, 1916.)—During recent years the practice of basing comparisons of various types of lamps and illuminating engineering calculations on the conception of the flux of light has made great progress. The lumen, originally proposed by Professor Blondel at the International Electrical Congress at Geneva in 1896, has now become a much more familiar unit to lighting engineers. The general impression at that time was undoubtedly that the expression of illuminating power in terms of lumens is the more accurate and scientific method, but that the candle-power, being now a well-understood and familiar term, could not be readily displaced. While, therefore, scientific men are turning towards the use of the lumen for accurate comparisons, in dealing with the general public an educational campaign must be undertaken in order to achieve the desired alteration gradually.

As a substitute for such terms as "candle-power per square inch" and "equivalent foot-candles" for expressing brightness, the Illuminating Engineering Society in the United States suggests as a unit "lambert, which is the brightness of a surface emitting one lumen per square centimeter of radiating surface."

A New Method of Refrigeration. W. H. EASTON. (*Scientific American*, vol. cxv, No. 11, September 2, 1916.)—The usual present practice in refrigeration is to employ an easily compressible gas, such as ammonia, carbon dioxide, or sulphur dioxide, liquefy it under pressure, and after cooling allow it to vaporize

under reduced pressure. The heat from this vaporization is absorbed from the surrounding medium, usually brine, and is used as the actual refrigerant. The newly developed system of refrigeration differs radically from this by using neither gas nor high pressure, but produces low temperatures solely through the evaporation of water. This process is a reversion to the earliest known method of cooling water, that of placing it in a porous vessel exposed to a draught of air. Only one improvement is introduced in the new system; the water is evaporated in a partial vacuum instead of at atmospheric pressure, the rate of evaporation being thus considerably increased. At a pressure of 0.0886 pounds per square inch, water boils at 32 deg. Fahr. Much lower temperatures, however, are attainable with compression machines.

A number of attempts have been made in the past to apply this well-known principle, but they have all failed through the want of a suitable air pump. The success of the new system rests on the employment of the centrifugal air pump invented several years ago by Maurice Leblanc. One of the obvious advantages of this type of installation is in the elimination of a dangerous gas carried at high pressure. On shipboard, especially war ships, this point is of great importance.

Coal Gas as a Motor Fuel. ANON. (*Motor Traction,* vol. xxiii, No. 601, September 6, 1916.)—In these times when every kind of substitute for petrol is being tested either for mixing purposes or as a whole fuel, it will be of interest to consider whether there are any commercial possibilities in the use of coal gas as a fuel for commercial vehicles. Mechanically, there is nothing to prevent the use of gas in internal combustion engines, as the alterations required would probably be only to the jet and the air supply, and the provision of a gas control valve between the gas cylinders and the carburetter; but commercially the increase of dead load which must reduce the carrying, and consequently, the earning, power of the vehicle, and a rise in such costs as tire charges, must be looked on as making the proposal unsound for the ordinary commercial vehicle.

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SCIENTIFIC RESEARCH IN RELATION TO THE INDUSTRIES.*

BY

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INDUSTRY, and with it all our modern civilization, depends on engineering. Engineering however is nothing but applied science, and science thus is the foundation, scientific research the ultimate means which have created our civilization. Through ages, the chief homes of scientific research have been the universities and other educational institutions. During the last generation however, the industrial development has been so rapid, and the demand for the results of scientific research so great and urgent, that the universities have not been able to supply it, and the industries, especially the more powerfully organized modern industries, as electrical engineering, chemistry etc., had to enter the field of scientific research. The country's educational institutions did not advance in fostering scientific research to the same degree as the industries advanced, and many universities and educational institutions rather retrograded in scientific research, became submerged in a false commercialism which figured the output of the college in student hours per professor, judged effi-

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ciency by the percentage of students graduated, and altogether too often wasted the university's best assets, its professors. Thus we find in our colleges men who had shown themselves capable as investigators to do scientific research work of the highest order, overloaded with educational or administrative routine, and deprived of the time for research work. Private industries rarely commit such crimes of wasting men on work inferior to that which they can do industrial efficiency forbids it.

Thus, when with the advance of industry a more rapid extension of our scientific knowledge was demanded, than given by the educational research institutions, scientific research laboratories were established in the industries. Some of them very soon showed their ability of producing scientific work of high character. As illustration I may mention, how an entire new branch of chemistry, the chemistry of the free atom, has resulted from the work of Langmuir in the Electrochemical Research Laboratory of the General Electric Company, and has been communicated to the literature by numerous papers.

However, these scientific research laboratories of the industry represent only a part, often the minor part of the research work done within the industry, and in many places throughout the industrial organization opportunity is afforded for the right men to carry out scientific research. Thus in the materials testing laboratories of our industrial corporations, in their standardizing laboratories, their apparatus testing departments, development sections and laboratories, etc., research work is being carried out, and as a rule is encouraged by the corporations.

Referring only to the field of electrophysics, most of our knowledge of the phenomena of electric waves and impulses in circuits, of magnetism, of dielectric phenomena etc., has come from this source.

When speaking of industrial research laboratories, we must not forget the private testing laboratories, development laboratories etc., which have been established and which to the smaller industrial organization take the same position, and do the same work, as their own laboratories to the great industrial corporations.

Theoretically, there is a limitation imposed on scientific research work in industrial establishments: It should be of such character, that it may lead to results which are industrially useful. In reality however, this is no limitation at all, but there is no

scientific investigation, however remote from industrial requirements, which might not possibly lead to industrially useful developments: and obviously no immediate or direct usefulness is expected: any investigation offering a definite prospect of industrial utility, is not scientific research, but is industrial development or design. Experience indeed has shown, that it is rare that sooner or later some industrially valuable results do not follow, no matter how abstruse and remote from apparent utility a scientific investigation may appear, and any scientific research whatsoever thus is industrially justified.

To illustrate, when by the Consulting Engineering Laboratory of the General Electric Company, research work was undertaken on the electrostatic corona and in general on the dielectric phenomena in the air, no immediate or direct benefit could be seen for the industrial company which financed the work, but it was justified by the consideration that a greater knowledge of these phenomena may extend the economic limits of long distance power transmission and thereby increase the industrial demand for transmission apparatus. Nevertheless, before the research was completed—if research can ever be considered completed—it had led to a redesign of practically all high voltage transmission apparatus and thus proven essentially valuable in industrial design.

Some research work can be carried out more efficiently by educational institutions, others by the industry. In general, for industrial research, better facilities in materials and in power are available, but high class skilled labor, of investigators and research men, such as available in university research by the graduate students, is expensive in the industry. Thus researches requiring little in facilities, but a large amount of time and attention of research men, are especially adapted to educational laboratories, while investigations requiring large amounts of material or of power rather than time of the investigators, are specifically adapted to the industry, and often beyond the facilities of the educational institution. Efficiency thus should require a division of research between educational and industrial laboratories in accordance with their facilities, and where this is done, the results are splendid. Thus for instance, the phenomena of the dielectric field beyond the elastic limit, or in other words those of the disruptive effects in air and other dielectrics under high electric stress, were almost entirely unknown a very few years ago, and it was

even unknown whether there is a definite dielectric strength of materials, analogous to the mechanical strength. This field has been very completely cleared up, and a comprehensive knowledge of the phenomena of the dielectric field gained, not only under steady stress, but also under oscillating stress, and under the transient stress of sudden electric blows or impulses, ranging down to the time measured by micro-seconds, as the result largely of the work of an industrial research laboratory—The Consulting Engineering Laboratory of the General Electric Company under Mr. F. W. Peek—and an educational laboratory—Johns Hopkins University under Professor Whitehead—both laboratories working independently and devoting their attention to those subjects, for which they are specifically fitted, though naturally often overlapping and checking each other.

Unfortunately, this limitation of research work in accordance with the available facilities is not always realized, and especially educational institutions not infrequently attempt research work, for which industrial laboratories are far better fitted, while research work for which the educational institution is well fitted, which the industry needs but can not economically undertake, is left undone. It is usually the desire to "do something of industrial value" which leads universities to undertake investigations on railroading and similar subjects, in which the probability of adding something material to our knowledge is extremely remote, or to undertake investigations on industrial iron alloys in competition with the vastly greater and more efficient research of industrial laboratories in this field of magnetism, while all other magnetic research is largely neglected, our knowledge on the phenomena of magnetism therefore still very unsatisfactory, and it is obvious that a material advance can be expected only from a comprehensive study of the entire field of magnetism, and the little investigated non-ferrous magnetic materials thus would be the ones most requiring study.

The closer relation of industrial research laboratories to the engineering practice leads to a tendency which in general may be expressed by saying, that in the results of industrial research, the probable error is greater, but the possibility of a constant error less than in educational research. In any investigation, typical conditions are selected. As these conditions naturally never can be perfect, two ways of procedure are feasible: either to in-

vestigate the errors and disturbing factors, and correct for them or to select the condition of experiment so that the disturbing factors are negligible, for instance experiment on a large scale. The latter method can not give as high accuracy as the former, but the former method, while theoretically more accurate, may give a constant error, possibly of hundreds of per cent., if some of the assumptions on which the corrections are based, are not completely justified. Industrial research leans towards the first method, as giving results which are safer in reliability, even if somewhat less accurate, while educational research leans towards the method of applying corrections. As illustration, in magnetic investigations, the effect of joints in the magnetic circuit, of joke, etc., may be determined and corrections for it applied or such a magnetic circuit may be chosen, that the effect of joints etc. is negligible, and can be neglected, or taken care of by a correction which is so small that its accuracy is not material.

In industrial research, the liability exists of limiting the work into such a narrow field, that it has little general scientific value: for instance, to determine the hysteresis loss in a magnetic material, without determining the magnetization curve. In educational research inversely there is sometimes the tendency to generalize beyond the limits justified, and so draw wrong conclusions. For instance, numerous investigations have been made and conclusions drawn therefrom in treatises on "the arc," while in reality the investigation was made with the carbon arc only, applies only to this kind of arc, and as the carbon arc is not typical but rather exceptional, for most other arcs the conclusions are wrong.

As regards to the quality of the scientific research work done in industrial organizations compared with that in educational establishments, there is no material difference, but the work done in the industry, just as that done in universities, varies from scientific research of the highest quality, down to investigations which are of little, if any value, investigations crude and inaccurate or directly erroneous in premises, in method and in results and their interpretation, or investigations, which while correctly conceived and correctly made, are useless, because essential conditions have not been controlled or recorded. Still worse are those pseudo scientific investigations occasionally met, which own their conception to the desire of self-advertisement or are made for commercial or legal purposes, such as, for instance, to

give the appearance of a scientific standing to some theory which some inventor had recorded in his patents. Such work—met occasionally, though less and less frequently—in industrial as well as in educational institutions, is the one which tends to discredit scientific research in the eyes of the layman, who can not discriminate between science and pseudo science.

The essential difference between industrial and educational research however is met in their method of publication: the publication mediums of scientific research carried on in educational institutions are the scientific publications published more or less under the direction or supervision of universities, while the publication mediums of the scientific research carried on in the industry are the technical or engineering papers, and only occasionally an abstract reaches the scientific publications. Unfortunately a large number of the scientists still look on publications in the technical press as unscientific, take no cognizance of it, do not recognize it in scientific abstracts, reviews, etc., and as the result, a large and steadily increasing part of the scientific research of the country is practically lost to the scientists, is not available or easily accessible, by not being recorded, abstracted or indexed in the records of scientific progress. If for instance in the tables of physical constants, published only a few years ago, under "hysteresis" are published the losses in a Siemens cable transformer (a type which had ceased to exist a quarter of a century ago), and practically all that mass of data on magnetism, recorded in the engineering proceedings, neglected, apparently as not "scientific," it shows that there is something wrong with the attitude of those responsible for the records of science. Amongst the worst offenders in this unjustified exclusiveness are the physicists, while the chemists make a recommendable exception: In the "chemical abstracts" published by the American Chemical Society, the results of industrial research as well as those of the chemical university laboratories are recognized, and these abstracts are therefore comprehensive and valuable, which cannot be said of the abstracts of some other sciences. Possibly the reason is, because applied chemistry is chemistry just as well as theoretical chemistry, while applied physics goes under the name of engineering, and the average theoretical physicist is rather inclined not to recognize engineering as scientific. Some excuse hereof may be found in the nature of the two classes of publications, the physical science publications and

the engineering publications. The former accept for publication only scientific papers, exert a critical judgment, and the appearance in the scientific publication medium thus implies that the article, at least in the opinion of the editors, is of scientific value. This is not the case, and can not be the case with the engineering or technical publications: the technical press is the medium of all the publications of those engaged in the industry, from scientific research of the highest value, to mere commercial statements, and the appearance of an article in an engineering paper or transaction does not imply, nor intend to imply, that it is of scientific value, but the discrimination between scientific worth or otherwise, which in the scientific publications is attempted by the editors, has in the engineering press to be left to the reader or abstractor. If however, the purpose of the engineering publication is to bring all classes of industrial records, and it thus includes commercial and other articles, this is no justification to refuse recognition to scientific papers contained in the same publication, but rather makes it desirable, and indeed necessary in the interest of our nation's scientific efficiency, to find some means or organization to carry out this discrimination and make available to the scientific world at large, the scientific work contained in the annals of applied science, that is, engineering.

To conclude then: scientific research of the highest class is carried out to-day in our nation in educational institutions as well as in industrial organizations and private testing laboratories, and the scientific research work in the latter is increasing at a far greater rate than that in the former. The publication mediums of scientific research of industrial organizations are the engineering publications and transactions, and the failure, in many branches of science, of recognizing the engineering publications in the records of science, thus makes the records of science incomplete, and increasingly so, therefore seriously retards the progress of science, and with it that of applied science, that is, engineering, and as engineering is the foundation of our civilization, it constitutes a serious menace to our nation's progress.

It is therefore important that those scientists, who are engaged in keeping the records of science and making the results of scientific research available and easily accessible, should recognize all sources and records of scientific research, including those of

applied science, that is, the engineering publications, and should undertake the work reviewing the technical press as well as the purely scientific publications, judging and selecting from the former those publications which are of scientific value, and recognize them. Only then will our records of science be complete and thereby valuable.

Immediately, the question then arises, is not the keeping of records of sciences one of the most important and most valuable activities, which in the interest of our national progress could be undertaken by our national government, by the National Bureau of Standards, as the only body, which is unpartisan and unprejudiced, is by its nature in close contact and intensely interested in engineering, and at the same time has proven its scientific standing and ability of doing scientific work of the highest class, and thereby on judging on scientific work?

Tendencies in Street Lighting Practice. ANON. (*Electrical World.* vol. 68. No. 10. September 2, 1916.)—A study of data on street lighting practice, collected from more than 100 cities, ranging from metropolitan population down to 25,000 inhabitants, shows that practically all types of street illuminants formerly used are giving place to gas-filled incandescent lamps and the improved types of arc lamps. Although gas-filled lamps are very prominent among the recent installations, the number of magnetite lamps which have been recently installed is by no means small. This may be accounted for by the longer life electrodes that are now being furnished, which partly compensate for the handicap that this type of lamp suffers in competition with gas-filled united. At the same time there is evidence that increased confidence is being placed in gas-filled lamps, this being probably due to the increased lamp life which can be obtained by the development of improved methods of manufacture and improved forms of fixtures.

According to reports from various companies during the year, and from organizations, there is an increased tendency towards ornamental lighting. Generally single lamps or, at most, double-lamp posts are being adopted instead of clusters, which were popular several years ago. The introduction of gas-filled lamps has in general resulted in increasing the candlepower used rather than in decreasing the wattage. Most of the gas-filled lamps have been of the series type, but multiple units are employed in central districts.

THE CONDENSATION PUMP: AN IMPROVED FORM OF HIGH VACUUM PUMP.*

BY

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IN a recent article in the *Physical Review*[1] the writer described a new form of mercury vapor vacuum pump, which was characterized by its extreme speed and the high degree of vacuum attainable. The preceding paper was merely a preliminary announcement of the new type of pump and no attempt was made to describe more than one form of the pump. In fact it was stated that " In a subsequent paper the writer will describe in more detail other modifications of mercury vapor pumps, some of which have marked advantages in simplicity of construction and reliability of operation over that shown here."

The object of the present paper is therefore to describe these improved pumps. Before doing this, however, it will be desirable to describe the original pump.

The original type of pump is shown diagrammatically in Fig. 1.

In this device a blast of mercury vapor passes upward from the heated flask A through the tubes B and C into the condenser D. Surrounding B is an annular space E connecting through F and the trap G with the vessel to be exhausted. The tube C is enlarged into a bulb H just above the upper end of the tube B. This enlargement is surrounded by a water condenser J from which the water is removed at any desired height by means of the tube K which is connected to an aspirator. The mercury condensing in D and H returns to the flask A by means of the tubes L and M. The tube N connects to the " rough " or " backing" pump which should maintain a pressure considerably lower than the vapor pressure of the mercury in A.

This pump operated extremely satisfactorily but was rather difficult to make. Trouble was frequently experienced by some

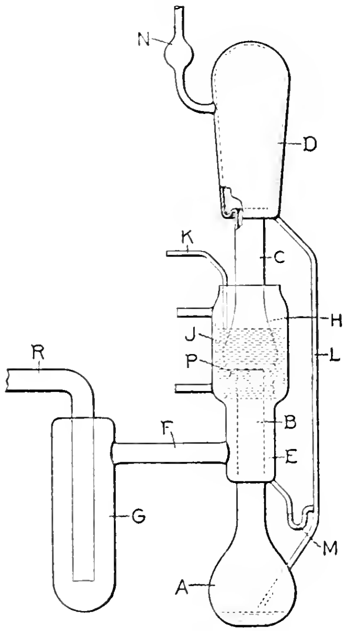
* Communicated by the author.

[1] Langmuir, Phys. Rev. 8, 48, (1916).

liquid mercury collecting at the bottom of the annular space *E*. This mercury by being in contact with the hot tube *B* gave off vapor which produced a blast passing upwards into the annular space *E*. Some of this mercury vapor flowed out along the tube *F* and interfered with the free passage of gas from *F* into the pump.

This difficulty may be avoided by the construction shown in Fig. 2. A circular trough, separated from *B*, is provided in

FIG. 1.



First form of condensation pump.

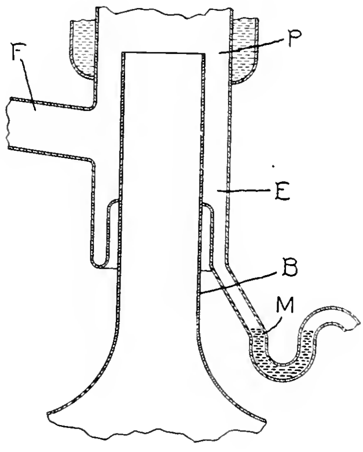
which the mercury may collect before flowing out through *M*. This prevents the mercury from being heated to a temperature high enough to give off troublesome quantities of vapor. In pumps of the type shown in Fig. 1 the difficulty could be easily overcome by directing a jet of air against the glass walls of the annular space *E* just below its junction with *F*. Tilting the apparatus slightly so that the mercury drained out more readily into the tube *M* also proved useful.

THE IMPROVED TYPE OF GLASS PUMP.

To completely avoid these difficulties the design shown in Fig. 3 was adopted. In this pump, mercury vapor from the flask *A* is carried through the thermally insulated tube *B* to the nozzle *L*. The vessel to be exhausted is connected to *R*. The gas from this vessel passes through the trap *G* and the tube *F* into the annular space *E*. At *P* this gas comes into contact with the mercury vapor blast issuing from the nozzle *L* and is thus forced *outward* and *downward* against the walls of the tube *C* and is finally driven down into the space *D* from which it escapes into the rough pump connection *N*. The mercury which condenses on the sides of the water-cooled tube *C* passes back through the tube *M* into the boiler *A*.

By this construction none of the mercury which condenses

FIG. 2.



Special construction designed to prevent overheating of the condensed mercury.

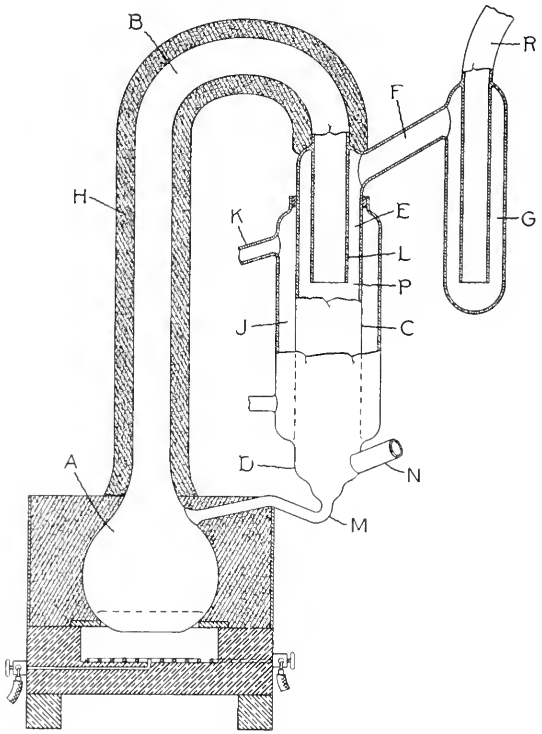
passes into the annular space *E* and thus the troublesome blast of mercury into the tube *F* is wholly avoided. The glass-blowing work on this type of pump is also much less difficult than on the earlier type.

In the pump shown in Fig. 1 a part of the mercury vapor condensed on the walls of the enlargement *H*, but the larger part passed up into the air-cooled condenser *D*. In the newer pump (Fig. 3) the enlargement of the tube *C* and the second condensing chamber are eliminated entirely. This greatly simplifies the con-

struction without materially affecting the operation of the pump. It is true that the speed of operation appears to be somewhat higher in the type containing the enlargement, but the speed of these pumps is usually so excessive even without the enlargement that a further increase in speed serves no useful purpose.

In order that the pump may functionate properly it is essential that the end of the nozzle *L* (Fig. 3) shall be located below

FIG. 3.



Improved form of condensation pump.

the level at which the water stands in the condenser *J*. In other words, the overflow tube *K* must be placed at a somewhat higher level than the lower end of the nozzle as is indicated in the figure. The other dimensions of the pump are of relative unimportance. The distance between *L* and *D* must be sufficiently great so that no perceptible quantity of gas can diffuse back against the blast of mercury vapor, and so that a large enough condensing area is furnished.

The pump may be made in any suitable size. Some have been constructed in which the tube *B* and the nozzle *L* were one and a quarter inches in diameter while in other pumps this tube was only one-quarter inch in diameter and the length of the whole pump was only about four inches. The larger the pump the greater the speed of exhaustion that may be obtained.

OPERATING CHARACTERISTICS.

In the operation of the pump the mercury boiler *A* is heated by either gas or electric heating so that the mercury evaporates at a moderate rate. A thermometer placed in contact with the tube *B*, under the heat insulation, usually reads between 100° and 120° C. when the pump is operating satisfactorily. Under these conditions the mercury in the boiler *A* evaporates quietly from its surface. No bubbles are formed so there is never any tendency to bumping.

Unlike Gaede's diffusion pump, there is nothing critical about the adjustment of the temperature. With an electrically-heated pump in which the nozzle *L* was 7/8 inch in diameter, the pump began to operate satisfactorily when the heating unit delivered 220 watts. The speed of exhaustion remains practically unchanged when the heating current is increased even to a point where about 550 watts is applied.

The back pressure against which the pump will operate depends, however, upon the amount and velocity of the mercury vapor escaping from the nozzle. Thus in the case above cited, with 220 watts, the pump would not operate with a back pressure exceeding about 50 bars,[2] whereas with 550 watts, back pressures as high as 800 bars did not affect the operation of the pump.

GENERAL THEORETICAL CONSIDERATIONS REGARDING VACUUM PUMPS.

Vacuum pumps are characterized principally by three factors.

1. *Back pressure* against which the pump may be operated. This is the pressure on the exhaust side of the pump as for example at *N* in Fig. 3.

[2] The bar is the C. G. S. unit of pressure: one degree per sq. cm. One bar is equal to a pressure of .00075 mm. of mercury or about one millionth of an atmosphere.

2. *Speed of the Pump.*—Gaede has defined, S, the speed of a vacuum pump by the equation

$$S = \frac{V}{t} \ln \frac{p_1}{p} \tag{1}$$

where t is the time required for the pump to reduce the pressure from p_1 to p in a vessel having the capacity V. The speed is thus measured in cu. cm. per second.

In the case of a piston pump this is approximately equivalent to the piston displacement per second.

3. *Degree of Vacuum Attainable.*—This is the lower limit to the pressure which may be obtained in a closed vessel connected to the pump.

For convenience we shall refer to the back pressure acting on the pump as the *exhaust pressure* while the pressure at which the gas enters the pump we shall call the *intake pressure.*

Most mechanical pumps of the piston type are built to exhaust at atmospheric pressure. But mechanical rotary pumps are frequently designed to be used in series with "rough pumps" in which case they operate with an exhaust pressure of a few hundredths of a megabar (1-5 cm. of mercury).

Newer forms of pump, such as Gaede's molecular pump and diffusion pump require still lower exhaust pressures (approximately 10–100 bars, roughly 0.01 to 0.1 mm. of mercury). Such pumps are always used in series with good mechanical pumps.

The type of mercury vapor pump shown in Fig. 3 operates with exhaust pressures ranging from 50 to 800 bars depending upon the amount of heat supplied to the boiler A.

With the exception of Gaede's molecular pump, which gives a maximum speed of about 1300 Cc. per second, mechanical high vacuum pumps have not had speeds exceeding 100 or 200 Cc. per second. Gaede's rotary mercury pump, for instance, gives a speed of about 120 Cc. per second. In nearly all cases the speed of a pump is practically independent of the exhaust pressure against which it operates unless this is raised above a certain rather critical value at which the pump ceases operating satisfactorily.

With most types of vacuum pump the degree of vacuum attainable depends to a large extent on the exhaust pressure used. This is usually due to leakage back through the pump. In the Gaede molecular pump, operating at low pressures, there is a

strict proportionality (about 50,000 : 1) between the exhaust pressure and the lowest attainable intake pressure.

When a pump has lowered the pressure nearly to its limiting value the speed of *exhaustion* decreases even though the *speed of the pump* remains the same. If S is the "speed of the pump" and E is the speed of exhaustion, then for a pump with which the lowest attainable pressure is p_0 we may define E and S as follows:

(2) $$S = V \frac{d \ln (p - p_0)}{dt} = \frac{V}{p - p_0} \frac{dp}{dt}$$

(3) $$E = V \frac{d \ln p}{dt} = \frac{V}{p} \frac{dp}{dt}.$$

From these we obtain

(4) $$E = S \left(1 - \frac{p_0}{p}\right)$$

The "speed of the pump," S, thus defined, usually remains practically independent of the pressure. If $p_0 = o$ is the limiting value of the pressure then the "speed of exhaustion" E is identical with S, the speed of the pump. In other cases the speed of exhaustion decreases as the pressure approaches p_0 and becomes zero when the limiting pressure is reached.

In operating vacuum pumps of high speed it is essential to use tubing of large diameter between the pump and the vessel to be exhausted if full advantage is to be taken of the speed of the pump. Knudsen[3] has calculated according to the kinetic theory the rate at which gases at low pressures can flow through tubing and has thoroughly checked these theoretical results by careful experiments.

Knudsen considered especially the "molecular flow" of gases through tubes at pressures so low that the collisions of the gas molecules with each other are of relatively rare occurrence as compared with the collisions between the gas molecules and the walls of the tubes. This molecular flow takes place at pressures at which the "mean free path"[4] of the molecules is large compared to the diameter of the tube.

Knudsen finds that the quantity of gas q which flows per second through a tube is given by the equation:

(5) $$q = \frac{p_2 - p_1}{W \sqrt{\frac{1}{\rho_1}}}.$$

[3] Ann. Physik. **28**, 76 (1909).

[4] See Dushman Gen. Electric Rev. **18**, 1042 (1915).

The quantity of gas q is measured by the product of volume and pressure. Thus

$$q = \frac{d(pV)}{dt}. \tag{6}$$

The pressure is preferably to be expressed in bars (dynes per sq. cm.). ρ_1 is the density (grams per cubic cm.) of the gas at unit pressure. From the gas law $pV=RT$ it is easily seen that the density of a gas is given by

$$\rho = \frac{pM}{RT} \tag{7}$$

where M is the molecular weight, T is the absolute temperature and R is the gas constant 83.15×10^6 ergs per degree. If we place $p=1$ we obtain

$$\rho_1 = \frac{M}{RT}. \tag{8}$$

In equation 5, W is the "resistance" which the tube offers to the flow of gas.

Knudsen finds that it is equal to

$$W = \frac{3\sqrt{\pi}}{8\sqrt{2}} \int \frac{o}{A^2}\,dl = 0.4700 \int \frac{o}{A^2}\,dl \tag{9}$$

where A is the area and o is the perimeter of the cross section of the tube. For circular tubes of diameter D and length L this becomes

$$W = \frac{6}{\sqrt{2\pi}} \frac{L}{D^3} = 2.394 \frac{L}{D^3}. \tag{10}$$

In the case of openings in thin plates Knudsen[5] gives

$$W = \frac{\sqrt{2\pi}}{A} = \frac{2.507}{A} \tag{11}$$

where A is the area of the opening.

Combining Equations 5, 8, 10 and 11 gives, for long circular tubes:

$$q_1 = \frac{\sqrt{2\pi}}{6} \sqrt{\frac{RT}{M}} \frac{D^3}{L} \left(p_2 - p_1\right) = 3809. \sqrt{\frac{T}{M}} \cdot \frac{D^3}{L}\left(p_2 - p_1\right) \tag{12}$$

and for openings in plates:

$$q_2 = \sqrt{\frac{RT}{2\pi M}} \cdot A\,(p_2 - p_1) = 3638. \sqrt{\frac{T}{M}} \cdot A\,(p_2 - p_1). \tag{13}$$

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[5] Ann. Physik. **28**, 999, (1909).

These equations are strictly accurate only when the diameter of the tube or opening is very small compared to the mean free path. From Knudsen's experimental data, however, it may be shown that as long as the mean free path is not less than 0.4 of the diameter of the tube, the Equation 12 gives results accurately within about 5 per cent. With air at room temperature and at a pressure of p bars the mean free path λ is $\lambda = 8.6/p$ centimeters.

Thus in the case of a tube one centimeter in diameter the Equation 12 would be accurate within 5 per cent. for all pressures below about 21 bars.

At higher pressures the quantity of gas flowing through a tube becomes much greater than that calculated by Equation 12. For these higher pressures the flow may be calculated from the viscosity η by Poisseuille's equation:

$$q_3 = \frac{\pi}{128} \frac{D^4 p}{\eta L} (p_2 - p_1) \tag{14}$$

where q is expressed in the same units as in Equation 5. This equation is of a totally different form from those applicable at low pressures. To make this clearer let us apply these equations to the case of air at room temperature (M=28.8; T=293). The viscosity η of the air at 20° C. is $181. \times 10^{-6}$ (C. G. S. units). Equations 12, 13 and 14 thus become

$$q_1 = 12130. \frac{D^3}{L} (p_2 - p_1). \tag{12a}$$

$$q_2 = 11700\, A\ (p_2 - p_1). \tag{13a}$$

$$q_3 = 136. \frac{D^4}{L} p(p_2 - p_1). \tag{14a}$$

With a tube 1 cm. in diameter and 10 cm. long with a difference of pressure ($p_2 - p_1$) of 1 bar we find $q_1 = 1213.$ Cc. per second, and $q_3 = 13.6\, p$ Cc. per second. These represent the quantities of gas flowing through the tubes measured in terms of the volume which the gas would occupy at one bar pressure. If the volumes of gas were measured at atmospheric pressure (10^6 bars) the volumes would be one millionth as great. In other words, at very low pressures 0.001213 Cc. of gas per second would flow through the tube, while at atmospheric pressure ($p = 10^6$) 13.6 Cc. per second would flow, or more than 10,000 times as much gas.

This indicates the relatively enormous resistance which tubes offer to the passage of gases at very low pressures. It should

be noted, however, that this resistance increases as the pressure is lowered only until the state of molecular flow is reached while for lower pressures the resistance remains constant.

Let us now consider a pump having a speed S, connected to a vessel of volume V by means of a tube of diameter D and length L. What will be the rate at which the vessel is exhausted?

We will assume that the volume of the tube is negligible compared to the volume of the vessel, and that the limiting pressure for the pump is $p_0 = O$. We obtain from (2) and (6)

$$S_1 p_1 = \frac{d(pV)}{dt} = q \tag{15}$$

in which p_1 is the pressure at the pump intake and q is the quantity of gas which flows per second through the tube.

Now the pump, connected through the tube, exhausts the vessel V at a rate which is less than if the pump were directly connected to the vessel. The pump and tube together, however, constitute a system which is the equivalent of a pump of lower speed, say S_2. The rate at which gas leaves the vessel to enter the tube is thus $S_2 p_2$, where p_2 is the pressure in the vessel. This is also equal to q, the rate at which the gas passes through the tube. Thus we have

$$S_2 p_2 = q. \tag{16}$$

Solving (15) and (16) for p_1 and p_2 and substituting in (5), we obtain

$$\frac{1}{S_2} = \frac{1}{S_1} + W\sqrt{\rho_1} \tag{17}$$

The quantity $W\sqrt{\rho_1}$ represents the resistance to flow offered by the tube. The quantity $1/S_1$ must also be of the nature of a resistance: the resistance of the pump to the passage of the gas through it. That is, the pump itself may be looked upon as the equivalent of a very large, perfectly exhausted vessel connected to the apparatus to be exhausted by a tube offering a certain resistance. Knudsen has already defined the term resistance of tube by equation (9) and it is desirable to retain this definition, since resistance thus defined is a function only of the dimensions of the tube and not of the kind or temperature of the gas flowing through it.

By analogy with electrical usage, we may thus define $W\sqrt{\rho_1}$ as the "impedance" of the tube. This "impedance" will depend

on the temperature and nature of the gas in a way not entirely dissimilar to the way impedance depends on frequency. The quantity $1/S_1$ is thus to be called the "impedance" of the pump, and $1/S_2$ is the "impedance" of the pump and tubing in series.

In this way we may calculate the speed of exhaustion through complicated systems in much the same manner as the calculations are made for electrical circuits. The effect of two tubes or more in series is obtained by adding their "impedances." With tubes in parallel, their "admittances" (reciprocal of impedance) are added.

Since it is usually more convenient to deal with the speed of a pump rather than with its reciprocal, it will also be convenient to express the characteristics of tubes in terms of their "admittance." This is a quantity of the same kind as S, the speed of the pump. In general, the "admittance" of a tube or opening may be defined by

$$S = \frac{q}{p_2 - p_1}. \tag{18}$$

Thus the admittance may be calculated for any case from Equations 5, 12, 13, 14, 12*a*, 13*a*, or 14*a*, merely by placing $p_2 - p_1 = 1$. As an illustration, in the case of a tube 1 centimetre in diameter and 10 centimetres long, with air at room temperature, we find from (12*a*) and (14*a*) that the admittance of the tube is 1213 Cc. per second at low pressures and $13.6 \times p$ Cc. per second at high temperatures.

If we place such a tube in series with a high vacuum pump having a speed $S = 1213$ Cc. per second, it will evidently cut the effective speed of the pump down to one-half its former value, namely, 606 Cc. per second.

Thus, with a pump which has a speed $S = 4000$. Cc. per second (and such speeds are easily attainable with mercury vapor pumps), if we wish to use a tube which does not reduce the effective speed by more than 10 per cent., we must use a tube which has an "admittance" of at least 36,000 Cc. per second. From Equation (12*a*), we see that for a tube of this kind D^3/L must be at least 2.97. Thus if a tube 30 cm. long is to be used, the diameter must be at least 4.5 cm.

These results indicate how seriously the speed of a mercury vapor pump may be limited by the resistance of the tubing unless this is of very great size.

We have thus far considered the action of the pump in lowering the pressure in a vessel. This process can not go on indefinitely, for the pressure finally becomes lowered to a point at which the leakage of gas into the apparatus prevents a further decrease of pressure. A stationary condition is then reached.

The leak which limits the pressure may be in the pump itself, or in the vessel being exhausted. The first case is equivalent to that we have already considered, in which there is a lower limit p_0 to the pressure attainable by the pump. The rate of flow of gas into the pump is then $S_1(p_1-p_0)$.

The gas leaking into the vessel does not, in general, pass through the walls of the vessel, but is given off from the walls of the vessel or from bodies within it. Let q_2 be the rate at which such gas escapes into the vessel. Then when a stationary condition has been reached, this rate will be equal to the rate at which the gas is being removed by the pump, namely, S_2p_2 where S_2 may be calculated from the speed of the pump S_1 and the "admittance" of the connecting tube. The lowest pressure obtainable in the vessel is thus

$$p_2 = \frac{q_2}{S_2} \tag{19}$$

This equation shows that the degree of vacuum which may be reached, even by a pump for which $p_0 = o$ is limited by the speed of the pump and the size of tubing between the vessel and the pump.

Measurements of pressure by various forms of supersensitive vacuum gages[6] have shown that the rate of evolution of water vapor from glass surfaces at room temperature is such that pressures below 0.2 bar could not be obtained even when using a molecular pump ($S_2 = 870$ Cc. per second) continuously for an hour. In this case we can calculate by Equation 19 that the rate of evolution q_2 must have been 170 Cc. (of gas at 1 bar pressure) per second. This corresponds to 0.00017 Cc. of gas at atmospheric pressure per second, or 0.62 Cc. of water vapor per hour. In this case the surface of glass was about 1800 sq. cm.

After heating the glass for half an hour or more to 360°, this evolution of water vapor (at room temperature) is reduced many thousand fold, but even then, it is not avoided entirely. The

[6] See, for instance, Dushman, *Phys. Rev.*, 5, 224 (1915).

limit to the pressure actually attainable by means of mercury vapor pumps seems to depend entirely upon this evolution of gas from the walls of the vessel and tubing, and not upon any inherent limitation in the pump itself.

Since the mercury vapor pumps are used in series with a rough pump, it is of interest to know what the speed of the rough pump should be to allow the mercury vapor pump to operate at maximum efficiency. Suppose we have a mercury vapor pump having, together with its connecting tubing, the effective speed S_2. Let this be connected to a vessel V containing gas at a pressure p_2. We have seen that the speed of mercury vapor pumps is practically independent of the exhaust pressure so long as this does not exceed a certain critical value, say p_c. Thus, to obtain the full effectiveness of the pump, it is only necessary to have a rough pump having sufficient speed (S_0) to maintain a pressure lower than p_c. Under these conditions the quantity of gas per second being delivered by the mercury vapor pump is S_2p_2, and this must be equal to the quantity removed by the rough pump, namely $S_0\, p_c$, from which we find

$$S_o = \frac{p_2}{p_c}\, S_2. \tag{20}$$

In other words, the maximum speed of the mercury vapor pump may be realized if the speed of the rough pump is less than that of the mercury vapor pump in the ratio $p_2 : p_c$. Ordinarily, the pressure p_c for a mercury vapor pump is about 200 bars, so that if it is used to exhaust a vessel at ten bars pressure the speed of the rough pump need not exceed one-twentieth of that of the mercury vapor pump. The only advantage, then, in using a faster rough pump is that the maximum speed may still be obtained even with pressures higher than 10 bars.

In case the speed of the rough pump is not sufficient to maintain a pressure lower than p_c, then the mercury vapor pump will not operate at maximum speed, but will deliver gas to the rough pump at such a rate that the pressure on the exhaust side of the mercury vapor pump will remain substantially constant at p_c. Thus the speed of the mercury vapor pump under these conditions will vary with p_2 according to the equation

$$S_2 = \frac{p_c}{p_2}\, S_o.$$

THEORY OF THE OPERATION OF THE CONDENSATION PUMP.

For a number of years the writer has been convinced that the collisions between gas molecules and a solid or liquid body against which they may strike, are in general almost wholly inelastic. Each molecule which strikes a surface thus *condenses* on the surface instead of rebounding, although it may subsequently re-evaporate. This condensation takes place just as well at high temperatures as at low, but at high temperatures the re-evaporation may occur so soon that it is difficult to detect the condensation. In this case the condensed molecules constitute an adsorbed film. The condensed particles, before they re-evaporate, are held to the surface by the same kind of forces as those which hold solid bodies together. This leads to a theory of adsorption which is in excellent agreement with experimental facts.

A general review of the above theory and of the evidences supporting it, has recently been published.[7]

It was by a direct application of these ideas that the writer was led to construct a high speed mercury vapor pump.

Gaede,[8] in connection with a study of the diffusion of gases through mercury vapor at low pressures, devised a new form of high vacuum pump which he has called the "diffusion pump." Before describing the mercury vapor diffusion pump, Gaede illustrates the principles underlying the action of such pumps by means of the water vapor pump shown diagrammatically in Fig. 4. A blast of steam passes through the tube AB, past the porous clay diaphragm C. The vessel to be exhaused is connected to the tube E and the appendix D is cooled by a mixture of ether and solid carbon dioxide. Steam diffuses through the diaphragm from left to right and is condensed at D and is thus prevented from passing into E. On the other hand, the air in the vessel to be exhausted passes into C and D and diffuses through the diaphragm from right to left into the steam, where it is carried away by the blast of steam. By a pump of this type Gaede was able to obtain an X-ray vacuum in about two hours. The great fault of this pump was its slow speed.

Gaede develops a simple theory of the pumps which use a clay

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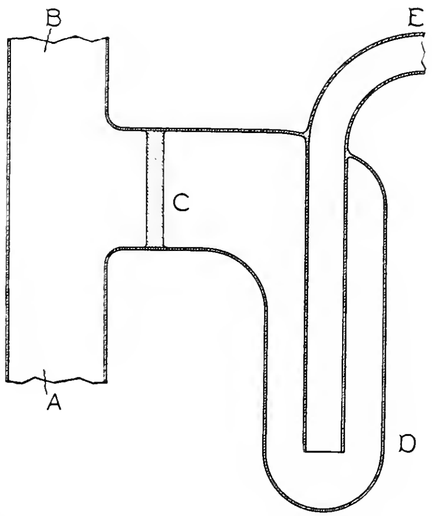
[7] The Evaporation, Condensation and Reflection of Molecules and the Mechanism of Adsorption. Phys. Rev. **8**, 149 (1916).

[8] Ann. Physik. **46**, 357 (1915).

diaphragm and finds that the speed can be increased either by increasing the surface of the diaphragm or by decreasing its thickness. If the thickness could be made zero, according to this simple theory, the speed would become infinite. He concludes that this equation does not apply to this case, and therefore proceeds to derive another, based on the kinetic theory. According to this theory, a porous diaphragm is equivalent to a large number of openings of dimensions comparable with the mean free path of the molecules. Gaede therefore calculates the rate at which one gas diffuses into a small hole in a thin plate out through which a second gas is escaping. In this way he finds that the first gas

FIG. 4.



Diagrammatic representation of one form of diffusion pump.

diffuses in at a maximum speed when the size of the opening is approximately equal to the mean free path of the second gas.

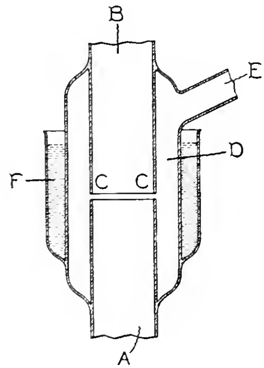
He thus determines the construction which will give a *diffusion* pump of the maximum speed. The design adopted for the mercury vapor diffusion pump is essentially that shown in Fig. 5. A blast of mercury vapor passes up through the tube *AB* past the narrow circular slit *C*. A part of the mercury vapor passes out through this slit and condenses on the water-cooled surface *D*. The gas from the vessel to be exhausted passes through *E* and *diffuses into the slit C against the escaping blast of mercury vapor.* After it enters *C* it is carried away from the slit by the

blast of mercury vapor and is thus effectively prevented from returning back through the slit.

It is evident that the speed with which the gas from E diffuses into the slit will have a maximum value for some particular width of slit. If the slit is too wide, the blast of mercury vapor escaping from it will be of such a volume that the gas molecules will not be able to diffuse appreciably against it. Gaede calculates and then shows experimentally that the maximum speed is obtained when the width of the slit is made approximately equal to the mean free path of the molecules in the mercury blast AB.

In the actual operation of the pump, Gaede finds it best to use such a pressure of mercury vapor that the maximum speed is

FIG. 5.



Diagrammatic representation of another form of diffusion pump.

obtained with a slit width of 0.012 cm. The maximum speed then obtainable is $S = 80$. Cc. per second.

Such relatively low speeds are inherent in pumps in which the gas must diffuse in through an opening against a blast of mercury vapor.

While constructing and operating a Gaede diffusion pump, it occurred to the writer that this serious limitation of speed could be removed if some other way could be found to bring the gas to be exhausted into the stream of mercury vapor. The action of a pump such as Gaede's diffusion pump really consists of two rather separate steps:

Process I. The process by which the gas enters the blast of mercury vapor.

Process II. The action of the blast of mercury vapor in

carrying the admixed gas along into a condensing chamber from which it cannot return to the vessel being exhausted.

The great advantage of the diffusion pump over all previous pumps lay in the remarkable effectiveness of the Process II. The limitations of the diffusion pump were imposed by the Process I.

Now the Process II in the diffusion pump is essentially similar to that used in commercial steam ejectors. In such ejectors, however, the Process I does not depend on diffusion, but on the lowering of pressure caused by the high velocity of the jet, in accordance with hydrodynamical principles (Bernoulli effect). The gas in an ejector is thus sucked into the jet because the *pressure in the jet is lower than that* of the gas in the vessel being exhausted. As the velocity of the mixed gases decreases in the expanding part of the ejector *C* (in Fig. 6), the pressure gradually increases up to that in the condensing chamber *D*.

Since the pressure in the jet must always be considerable, it is evident that the Bernoulli effect cannot be directly utilized to obtain a high vacuum. According to the kinetic theory also, the molecules in a jet of gas passing out into a high vacuum must spread laterally, so that there would be no tendency for a gas at low pressures to be drawn into such a blast.

In fact, it is easy to see that an ejector such as is shown in Fig. 6 could not be used to produce a high vacuum. Suppose, for instance, that a blast of mercury vapor passes through the tube *A* and escapes from *B* into the exhausted chamber *C*, and condenses at *D*. A large fraction of the atoms of mercury vapor escaping from *B* will have transverse velocity components, so that they will strike the walls of the outer tube at *K*. These will condense, but the heat liberated will cause the walls to assume a temperature comparable with that of the mercury vapor blast. The condensed mercury will therefore evaporate approximately as fast as it condenses. The atoms which evaporate are just as likely to leave the surface in a direction towards *E* as towards *C*. Therefore a large fraction of the mercury vapor which strikes the wall *K* will pass into the tube *E* and out through *F*, so that it will completely prevent the entrance into *E* of a gas at low pressures. Experiments have subsequently proved that this is exactly what happens when it is attempted to operate an ejector at very low pressure. Not only does the device fail to pump, but it is often impossible to get any gas to pass through the device, even when there is

a pressure of 100 bars or more at F and the pressure at D is held at 1 bar or less.

This reasoning indicates that the Bernoulli effect cannot be used to draw the gas into the blast (Process I). The main reason for this failure is the blast of gas which originates at K by the re-evaporation of the condensed mercury. If this re-evaporation could be prevented, the blast of gas from K to E would disappear

FIG. 6.

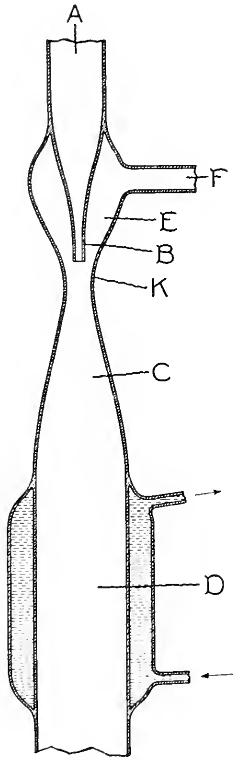


Diagram illustrating the action of an ejector.

and the gas from F would therefore meet no obstacle in passing into E and entering the stream of mercury vapor at K.

If it had been assumed that the mercury atoms striking K were *reflected* into E, then there would be no obvious means of preventing this reflection. But the work previously referred to had convinced the writer that reflection did not occur, and therefore indicated that to avoid this blast of mercury vapor into E it

would only be necessary to cool the walls of the outer tube at the point *K*.

In this way, the blast of gas into *E* is made to disappear and the gas from *F* therefore passes into *E* and towards *K*. Beyond the nozzle *B* the molecules of this gas are struck by the atoms of mercury escaping from *B* and are *forced outward* (not drawn inwards) against the walls of the outer tube at *K*. The gas molecules are then subjected to a continual bombardment from mercury atoms which have velocity components in the direction towards *C*. If the walls of the tube *C* are also water-cooled, the gas which enters at *F* is thus pushed along the walls of *C* and is finally driven into the condenser *D*.

This was the reasoning which led to the construction of the type of pump shown in Fig. 1. The very first pump constructed operated perfectly satisfactorily and gave a speed of about 1800 Cc. per second.

The action of the pump is based on radically different principles from that of the ejector. The most essential element in the operation seems to be the condensation of the mercury vapor at *K* and the maintenance of a temperature in this region so low that the condensed mercury does not re-evaporate. It is therefore suggested that pumps based on this principle should be called *Condensation Pumps.*

The distinction between the condensation pump and the ejector is clear when we realize that in the ejector there is no necessity for cooling the walls of the tube at *K*, Fig. 6, whereas the condensation pump entirely fails to operate unless this is done. Furthermore the effectiveness of the ejector depends on the flare of the tube *C* between *K* and *D*, whereas this flare is entirely unnecessary in the condensation pump. In fact, since a large portion of the mercury vapor condenses on the walls at *K*, it is rather desirable to have a *decreasing cross section* between *K* and *D*. In the form of pump shown in Fig. 1, this contraction above the point *P*, Fig. 1, was actually employed. Subsequent experiment showed that it was unnecessary to provide two condensing chambers as in Fig. 1, but that the pump could be simplified as in Fig. 3.

If this later form of pump is examined during operation, it is seen that when there is a high vacuum on the intake side of the pump, practically no condensation of mercury takes place on the walls of the condenser *C* above the level of the point *P*. In other

words, *all* the atoms of mercury vapor leaving the end of the tube L have downward velocity components and therefore cannot pass up above the point P unless they first strike some body not having the corresponding downward velocity. If, however, the walls of the condenser are allowed to become heated, then the mercury atoms from L collide with mercury atoms evaporating from the walls (which do not have downward velocities) and as a result of these collisions a large fraction of this mercury vapor is deflected upward into the space E. This prevents gas from F from reaching the point P where it might be acted on by the direct blast from L.

When a small flow of gas is allowed to enter through R so that the intake pressure is maintained at about 100 bars, it is interesting to observe that the line of demarcation below which the condensation occurs loses its sharpness, and that a considerable quantity of mercury vapor condenses above the point P. This is due to the collisions between the mercury atoms from L and the gas molecules which are driven in close to the walls of the condenser C.

Another interesting fact may be observed by watching the operation of the condensation pump. The greater part of the mercury vapor which escapes from L condenses on the walls of C within a couple of centimetres below the end of the nozzle L. This indicates that the mercury atoms radiate out from the end of L in all directions and show no particular tendency to continue to move in the direction in which the nozzle is pointed. This is essentially different from what happens in injectors or ejectors. It is well known that when steam escapes from a straight tube into the open air, the jet of steam continues to move in a nearly straight line for a considerable distance from the nozzle before it mixes to a large extent with the air. This effect evidently entirely disappears at very low pressures. This fact is in accordance with the kinetic theory of gases. At very low pressures the density of the mercury vapor is extremely small, whereas the viscosity of the gas is practically as great as at atmospheric pressure. The frictional effects of the walls therefore entirely predominate over the inertia effect which at higher pressures leads to the jet formation.

Some special pumps have been built to operate by a combination of the injector and condensation pump principles so that very

much higher exhaust pressures may be used. In this way it has been possible to operate a single mercury vapor pump producing as high a vacuum as the ordinary type of condensation pump, but exhausting at a pressure of about 20 mm. of mercury. Further development work will be necessary, however, before these pumps become as satisfactory as a condensation pump backed up by a mechanical pump.

CONDENSATION PUMPS BUILT OF METAL.

The condensation pump lends itself admirably to construction in metal.

One type of pump which has proved relatively simple in construction and efficient in operation is shown diagrammatically in Fig. 7. A metal cylinder *A* is provided with two openings *B* and *C*, of which *B* is connected to the backing pump and *C* is connected to the vessel to be exhausted. Inside of the cylinder is a funnel-shaped tube *F* which rests on the bottom of the cylinder *A*. Suspended from the top of the cylinder is a cup *E* inverted over the upper end of *F*. A water-jacket *J* surrounds the walls of the cylinder *A* from the level of *B* to a point somewhat above the lower edge of the cup *E*.

Mercury is placed in the cylinder as indicated at *D*. By applying heat to the bottom of the cylinder the mercury is caused to evaporate. The vapor passes up through *F* and is deflected by *E* and is thus directed downward and outward against the water-cooled walls of *A*. The gas entering *C* passes down between *A* and *E* and at *P* meets the mercury vapor blast and is thus forced down along the walls of *A* and out of the tube *B*. The mercury which condenses on the walls of *A* falls down along the lower part of the funnel *F* and returns again to *D* through small openings provided where the funnel rests upon the bottom of the cylinder.

A more detailed drawing of the pump as actually constructed is shown in Fig. 8.

Pumps of this type have been made in several different sizes. A pump in which the funnel *F* is 3 cm. in diameter and the cylinder *A* is 7 cm. in diameter gives a speed of exhaustion for air of about 3000 Cc. per second and will operate against an exhaust pressure of 200–600 bars, depending on the amount of heat supplied to the mercury. The energy consumption ranges from 100 to 500 watts.

Very small pumps have also been constructed in which the tube *F* is only 0.6 cm. and the cylinder *A* is only 2 cm. in diameter. This type of pump gives a speed of about 200 Cc. per second.

DEGREE OF VACUUM OBTAINABLE.

The condensation pump resembles Gaede's diffusion pump in that there is no definite lower limit (other than zero) below which the pressure cannot be reduced. This is readily seen from its method of operation. A lower limit could only be caused by a diffusion of gas from the exhaust side (*N* in Fig. 3) back against the blast of mercury vapor passing down from *L*. The mean free path of the atoms in this blast is of the order of magni-

FIG. 7.

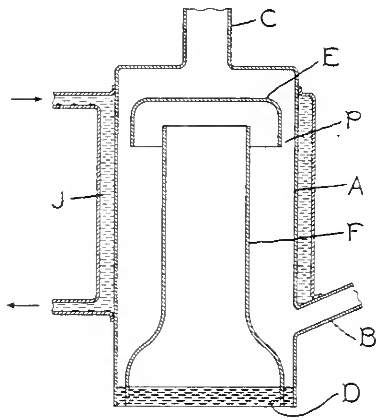


Diagram of condensation pump built of metal.

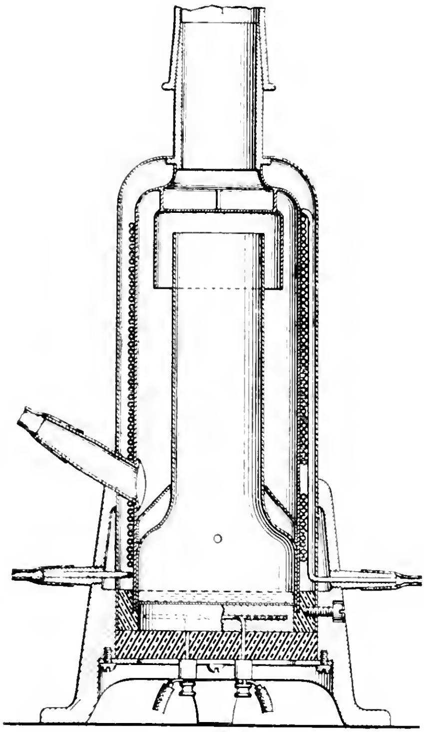
tude of a millimetre or less and the blast is moving downward with a velocity at least as great as the average molecular velocity (100 metres per second for mercury).[9]

The chance of a molecule of gas moving a distance about 4.6 times the mean free path without collision is only one in a hundred. To move twice this distance the chance is only 1 in 100^2, etc. If the mean free path were one millimetre, the chance of a molecule moving a distance of 4.6 cm. against the blast without collision would be 1 in 10^{20}. In other words, an entirely negligible chance.

[9] This is apparent when we consider that no appreciable number of atoms pass up into the space *E*.

However, if with any particular design of pump it should be found that gas does leak back against the blast of a vapor, it is a simple matter to increase the pressure in the blast or increase the distance against which the gas must pass back through the blast. Thus the construction adopted in Fig. 1 may be adopted where only a small part of the mercury is condensed close to the nozzle from which the vapor escapes, while the greater portion travels a considerable distance before condensing.

FIG. 8.



Condensation pump built of metal.

As a matter of fact, even in the type of pump with a single condensing chamber, such as shown in Figs. 3 and 7, there is evidence that the back diffusion is absolutely negligible under all normal operating conditions. Thus if a vessel is exhausted to .001 bar (the lowest pressure readable on a McLeod gage) while a good vacuum is maintained on the exhaust side of the pump, it is found, when the pressure on the exhaust side is gradually raised,

that the vacuum remains unchanged on the intake side until a relatively high pressure such as 200–600 bars on the exhaust side is reached. A very slight further increase in the exhaust pressure then causes a very great increase in pressure on the intake side. This result indicates that when comparatively low exhaust pressures such as 50 – 100 bars are used, the limiting pressure on the intake side, if it exists at all, must be extraordinarily low.

Of course it must be realized that the condensation pump like any mercury pump does not remove mercury vapor from the system to be exhausted. The vapor pressure of mercury at room temperature is in the neighborhood of 2 bars. By inserting a trap such as that indicated at *G* (in Fig. 3), between the pump and the exhausted vessel, this vapor pressure may be lowered. The following table gives the vapor pressures of mercury corresponding to different temperatures and indicates how completely mercury vapor may be eliminated by cooling the trap.

Temp.° C.	Vapor Pressure of Hg. in bars.[10]
−180 ° C.	2.3×10^{-24}
−78	4.3×10^{-6}
−40	0.0023
−20	0.029
−10	0.087
0	0.25
+10	0.65
+20	1.6
+30	3.7

For a very large number of experiments the presence of mercury vapor is not injurious. By use of solid CO_2 or liquid air the mercury vapor may be entirely eliminated.

As has been pointed out previously the vacuum actually attainable by the condensation pump is usually determined (according to Equation 19) by the rate at which gases are given off by the walls of the vessel being exhausted.

By means of a new type of vacuum gage devised by Dr. A. W. Hull of this laboratory, pressures as low as 10^{-5} bar, obtained by

[10] These vapor pressures are calculated from the formula

$$\log p = 11.27 - \frac{3243}{T}$$

which is obtained from data given by Knudsen (Ann. Physik. **29**, 179 (1909).

the condensation pump, have already been measured. There is little doubt but that pressures very much lower than this can be and have been obtained by cooling the bulb to be exhausted in liquid air so as to decrease the rate at which gases escape from the walls.

SUMMARY.

Two new types of condensation pump are described, one built wholly of glass and the other wholly of metal.

In these pumps a blast of mercury vapor carries the gas into a condenser. This action is similar to that in a steam ejector and in a Gaede diffusion pump. The method by which the gas is brought into the mercury vapor blast in the condensation pump is based on a new principle which is essentially different from that employed in the steam ejector or Gaede diffusion pump. In the new pumps the gas to be exhausted is caught by the blast of vapor and is forced by gas friction to travel along a cooled surface. By maintaining this surface at such a low temperature that the condensed mercury does not re-evaporate at an appreciable rate, it is possible to keep the mercury vapor from escaping into the vessel being exhausted. The action of this pump therefore depends primarily upon the fact that *all* the atoms of mercury striking a mercury-covered surface are condensed (no matter what the temperature), instead of even a fraction of them being reflected from the surface. It is for this reason that the term condensation pump is proposed.

The condensation pump is characterized by extreme speed (3000–4000 Cc. per second, or even more, if desired), by simplicity and reliability, and by the absence of lower limit (other than zero) to which the pressure may be reduced. By the aid of this pump pressures lower than 10^{-5} bars have been produced and measured.

To obtain the full benefit of the high speed of these pumps, it is necessary to use connecting tubing of very large size. Equations are given by which the effect on the speed of exhaustion produced by tubing of any given dimensions may be calculated.

The Future Prospects of Light Production. C. P. STEINMETZ. (*Proceedings of the Illuminating Engineering Society,* September 18–20, 1916. *American Gas Light Journal,* vol. cv, No. 13, September 25, 1916.)—Probably the most radical advance in illuminating engineering and light production that has been made through all the ages is embodied in the Welsbach lamp. It was the first time, outside of the temperature law, that energy had been conducted into radiation. We have a number of methods of light production which are not based directly on heat as an intermediate form. But still, modern lighting, especially electric lighting, is based on the temperature radiation; and in the field of temperature radiation or incandescent lighting, we probably consider the highest development of to-day, the highest efficiency of temperature radiators or illuminators represented by the acetylene flame and the gas-filled Mazda lamp. In the last fifteen years enormous advances have been made in increasing the efficiency of temperature radiation, and increasing the efficiency of the incandescent lamp from four watts per candle power up to that of the present lamp with less than half a watt per mean spherical candle power. It is not probable that the advance in temperature radiation in the near future will be nearly as radical. We appear to be approaching the limits of efficiency possible under the temperature radiation law, and it may be predicted that future advances will be measured in per cents rather than in the hundredths of per cents of the last fifteen years.

The temperature possible with hydro-carbon gases or vapor as a source of chemical energy necessarily is limited by the dissociation temperature of oxides of carbon and hydrogen in the acetylene flame. We are not far from those temperatures. In material, higher efficiency than given by the acetylene flame in light production under temperature radiation is not probable, except by using a radiator, using a combustible the oxide of which has a much higher dissociation temperature, such for instance as metallic magnesium. As a result of the present war, the commercial manufacture of magnesium has been developed to a considerable extent and it is quite likely that after the war when conditions have become normal, magnesium will be obtainable at prices comparable with those of aluminum. It is by no means impossible that if we realize such low prices of magnesium as appear possible under normal conditions, that magnesium as a combustible may become economically competitive as a light producer with the hydro-carbon flame. Perhaps after we have defined it broadly enough, chemical luminescence is not temperature radiation, because there is no temperature at which the radiation of the body would give a spectrum like that of the Welsbach mantle, because, at the temperature of the burning flame, these oxides, when heated electrically or protected from the flame gases do not luminesce.

ELECTROLYTIC DISSOCIATION IN NON-AQUEOUS SOLUTIONS.*

BY

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DURING recent years a great deal of work has been carried out in order to determine whether the laws which have been found to hold for electrolytes in aqueous solution also apply in the case of non-aqueous solutions. As a result of these investigations, in some cases it has been found the same laws which hold for aqueous solutions also apply to non-aqueous solutions; in many others this is apparently not true. Indeed, up to the present time, very few generalizations have been obtained. One of the most important generalizations that has been discovered is: a certain affinity between solute and solvent is necessary in order that conduction, that is, dissociation, may take place at all.[1]

Early Investigations.—One of the earliest and most systematic investigators in the field of non-aqueous solutions is Paul Walden, who, as early as 1899, found [2] that liquid sulphur dioxide has a remarkable power of dissolving the most varied substances, both inorganic and organic, the solutions often showing a characteristic color. Thus the iodides of sodium, potassium and ammonium dissolve in liquid sulphur dioxide forming yellow solutions. Among the organic compounds which are soluble in this solvent are alcohol, benzoic acid, phenol, ethyl acetate and aniline. The fact that the substances dissolved in this solvent readily react with one another indicates that they are dissociated. Thus, by double decomposition,

$$KI \times (CH_3)_4NCl = KCl \times (CH_3)_4NI.$$

All these substances are soluble in liquid sulphur dioxide, except potassium chloride which precipitates out of solution. The con-

* Communicated by Professor Creighton.

[1] Walker; J. Chem. Soc., **85**, 1082 (1904); Steele, McIntosh and Archibald; Proc. Roy. Soc., **74**, 325 (1905).

[2] Walden; Ber., **32**, 2862 (1899).

ductivity of sulphur dioxide solutions of many substances is large and, in some cases, greater than aqueous solutions of the same concentration. The increase of the molecular conductivity of these solutions with concentration is irregular, and in the case of the iodides much more marked than their aqueous solutions. The conductivity of ammonium, tetramethylammonium and tetraethylammonium iodides in liquid sulphur dioxide increases with the complexity of the cation. Since the difference between μ_{512} and μ_{16} for potassium iodide is greater in liquid sulphur dioxide than in water, it is probable that both the degree of dissociation and the electrolytic mobilities of the ions of the solute differ in the two solvents.

Later Walden [3] investigated the solvent property of a number of inorganic liquids, and determined the dissociation in the solutions by the conductivity method. Phosphorus trichloride and phosphorus tribromide were found to dissolve many organic compounds and the halides of arsenic, antimony and tin, but very few other inorganic compounds. Binary salts were found to dissociate to a considerable extent in phosphorus oxychloride. while ternary salts were observed to dissociate to but a slight extent. Arsenic trichloride was found to dissociate binary salts, but sulphuryl and thionyl chlorides had only a very slight dissociating power. Antimony trichloride yielded conducting solutions; the pentachloride did not.

Cady [4] observed that when a small quantity of a soluble salt (*e. g.*, sodium, potassium, silver, copper, barium, etc., salts) is added to liquid ammonia (spec. conductivity $= 71 \times 10^{-7}$) a solution of excellent conducting power is obtained. The presence of a small amount of water does not seem to have a measurable effect on the conductivity of either the ammonia or the substances dissolved therein. It is worthy of note that all the above mentioned dissociating solvents belong to the nitrogen or oxygen families.

Elaborate investigations in liquid cyanogen and hydrocyanic acid have been carried out by Centnerszwer, who found [5] that while the former has but a small dissociating power, the power of dissociation of the latter is even greater than that of water.

[3] Walden, Z. anorg. Chem., **25**, 209 (1900).
[4] Cady, J. Phys. Chem., **1**, 707 (1897).
[5] Centnerszwer, Z. physik. Chem., **39**, 217 (1902).

Thus, the equivalent conductivities of potassium iodide and trimethylsulphine iodide in liquid hydrocyanic acid, at 0°, are about four times as large as the corresponding values for aqueous solutions.

Dissociation of Complexes.—Solvents which do not dissociate ordinary electrolytes (salts, acids and bases) often cause certain complexes to dissociate to a large extent. For example, it has been shown [6] that although liquid bromine does not dissociate potassium bromide, tetramethylammonium iodide, trichloracetic acid, aluminum bromide, arsenic tribromide, or tin tetrabromide, concentrated solutions of the complexes $AlBr_7CS_2$ and $AlBr_5C_2H_5BrCS_2$ in this solvent exhibit a conductivity similar to that of typical salts in water. This behavior points to the fact that the complexes form addition compounds with the solvent, and that it is these that dissociate into ions.

Abnormal Electrolytes.—It has been found [7] that certain non-aqueous solvents, such as arsenic trichloride and sulphur dioxide, can dissolve and dissociate chlorine, bromine, iodine, sulphur, phosphorus, arsenic, antimony, and tin, substances which are neither acids, bases nor salts, and which do not possess any conductivity in aqueous solution. Thus in sulphur dioxide,

$$Br_2 = Br^+ + Br^-.$$

Substances which dissociate in this way are termed *abnormal electrolytes,* since the element itself must produce both anion and cation. Up to the present very little is known regarding abnormal electrolytes.

Influence of Concentration on Conductivity.—Just as in the case of aqueous solutions, the molecular conductivity of non-aqueous solutions usually increases with dilution. This behavior is illustrated by Table I, which contains some of the results of measurements made by Creighton [8] of the conductivity of acetophenone solutions of piperidine, camphorcarboxylic acid, bromcamphorcarboxylic acid and piperidine camphorcarboxylate, at 17°.

[6] Plotnikow, Ibid., **48**, 220 (1904).
[7] Walden, Z. physik. Chem., **43**, 385 (1903).
[8] Creighton, Ibid., **81**, 566 (1913).

TABLE I.

Dilution v	Molecular Conductivity $\mu \times 10^4$
PIPERIDINE	
2	10.74
4	18.16
8	30.08
CAMPHORCARBOXYLIC ACID	
2	58.2
4	79.2
8	100.0
16	107.5
32	111.7
BROMCAMPHORCARBOXYLIC ACID	
2.75	84.4
5.50	105.0
11.00	126.5
22.00	132.0
PIPERIDINE CAMPHORCARBOXYLATE	
2	344.8
4	350.4
8	406.4
16	492.8
32	585.6

In the case of non-aqueous solutions of a number of substances, the molecular conductivity has been found to decrease as the dilution increases. This decrease has been explained [9] on the assumption that the solute forms complexes with the solvent.

Conductivity of Salts.—It will be observed from the values for piperidine camphorcarboxylate, given in the preceding table, that, like in aqueous solution, the molecular conductivity of a salt of a weak acid and a weak base is considerably greater than that of either the acid or base alone. This behavior is more fully illustrated by Table II, which contains data obtained by Creighton [10] for acetophenone solutions of salts of camphorcarboxylic acid with a number of weak organic bases, at 17°.

[9] Steele, McIntosh and Archibald, Z. physik. Chem., **55**, 179, (1906); Sakhanov, J. Russ. Phys. Chem. Soc., **43**, 543.

[10] Creighton, Proc. and Trans. Nova Scotian Inst. Sci., **13**, 154 (1912).

TABLE II.

Base	Half-normal acetophenone solution. Mol. cond. of base. × 10⁴	Mol. cond. of carboxylate × 10⁴
Aniline	very small	72.2
Quinaldine	very small	139.6
Triisobutylamine	1.46	1128.2
Quinine	1.54	173.4
Quinidine	1.62	172.4
Nicotine	3.40	512.8
Conine	3.76	72.6
Tripropylamine	4.56	1439.4
Benzylamine	7.68	348.6
Piperidine	10.74	346.6

Although the conductivities of the carboxylates in Table II are twenty to several hundred times as great as those of the corresponding bases, the values are still very much smaller than in aqueous solutions of the same concentration.

Transport Numbers.—Many difficulties are encountered in making measurements of the transport numbers of the ions in non-aqueous solutions. Carrara [11] has been able to show, however, that in methyl alcohol the transport numbers of certain substances behave as if the solutions were more concentrated than corresponding aqueous solutions. Schlundt has found [12] that although the transport numbers of the ions of silver nitrate in various solvents are largely dependent upon the nature of the solvent, the values converge with increasing dilution. According to Franklin and Cady,[13] the velocities of a number of univalent ions in liquid ammonia (at $-33°$) are from 2.4 to 2.8 times as great as in aqueous solutions at 18°.

The Law of the Independent Migration of Ions.—Kohlrausch's law of the independent migration of ions has been found to apply to a number of non-aqueous solutions. As early as 1897, Carrara observed that the halogen ions have the same velocities in methyl alcohol as in water, and that the sodium and potassium ions have the same velocities when calculated from their different halogen salts. In other words, Kohlrausch's law applies to these solutions. The law has also been verified [14] for

[11] Carrara, Atti. accad. Lincei, **4**, 339 (1901).

[12] Schlundt, J. Phys. Chem. **6**, 159 (1902).

[13] Franklin and Cady, J. Amer. Chem. Soc., **26**, 499 (1904).

[14] Walden, Z. physik. Chem., **54**, 131 (1906).

solutions of a number of solutes in acetonitrile and epichlorhydrin. Dutoit and Gyr have shown [15] that the values for the equivalent conductivity of sulphur dioxide solutions of the bromides and iodides of potassium, rubidium, ammonium and tetraethylammonium conform with the law of the independent migration of ions. In their investigation of the conductivity of acetophenone solutions of a number of binary salts, Dutoit and Levier [16] have found that the molecular conductivity approaches a limiting value as in aqueous solutions. These limiting values have been found to satisfy the law of the independent migration of ions, but the ratios of the electrolytic mobilities of the ions of the salts have been found to differ from those in aqueous solutions. Although Kohlrausch's law applies to many non-aqueous solutions, solutions in a number of solvents have been investigated for which apparently this law does not hold even approximately.

Ostwald's Dilution Law.—Although the applicability of the dilution law to dilute aqueous solutions is substantiated by the results of a very large number of researches, the number of cases for which it holds in non-aqueous solutions is limited. It is possible that an extended study of this law with reference to non-aqueous solutions may lead to an explanation of the anomaly of strong electrolytes in aqueous solution. Wakeman [17] has found that the dilution law does not apply to strong electrolytes in mixtures of ethyl alcohol and water; and Walden and Centnerszwer [18] have observed that it is inapplicable to solutions of certain substances in liquid sulphur dioxide. On the other hand, Wildermann [19] has shown that this law holds for solutions of certain substances in absolute alcohol and in trichloracetic acid; and Godlewski [20] has obtained evidence that solutions of weak acids in ethyl alcohol and water obey the law. Dutoit and Gyr [21] have found that, above dilutions of 8000 liters, the dilution law is applicable to sulphur dioxide solutions of the iodides of certain alkali metals and to tetraethylammonium iodide.

[15] Dutoit and Gyr. J. Chim. phys., 7, 189 (1909).

[16] Dutoit and Levier, J. Chim. phys., 3, 435 (1905.

[17] Wakeman, Z. physik. Chem., 11, 49 (1893).

[18] Walden and Centnerszwer, Z. anorg. Chem., 30, 170 (1901).

[19] Wildermann, Z. physik. Chem., 14, 247 (1894).

[20] Godlewski, J. chim. phys., 3, 393 (1905).

[21] Dutoit and Gyr, J. chem. phys., 7, 189 (1909).

In an investigation on the conductivity of acids in absolute and aqueous alcohol, Goldschmidt[22] recently found that the behavior of the electrolytes is similar to their behavior in aqueous solution. The equivalent conductivities of the acids studied all approach limiting values as the dilution is increased. In Table III are given the equivalent conductivities at infinite dilution (Λ_0) and the dissociation constants (k) for a number of acids in absolute alcohol, at 25°.

TABLE III.

Acid	Λ_0	k
Picric	93	1.75×10^{-4}
Trichloracetic	88	1.5×10^{-6}
Trinitrobenzoic	86.5	7.0×10^{-7}
Dichloracetic	94	5.2×10^{-8}
Salicylic	86	2.2×10^{-8}

According to the recent investigations of Kraus and Bray[23] on the conductivity of dissociated substances in various solvents, all solutions of binary electrolytes obey the same dilution law. The mass action law (Ostwald's dilution law), however, is only obeyed at high dilutions; for higher concentrations the deviation from the mass action law is a function of the ionic concentration. For a given electrolyte, the trend of the conductivity curve for different solvents is determined by the dielectric constant of the solvent. The observed facts, both for dilute solutions and for solutions up to more than normal concentration, bear out the fundamental hypothesis of Arrhenius, according to which the dissociation of an electrolyte is measured by the conductivity ratio,—$\frac{\Lambda}{\Lambda_0}$

Chemical Activity.—Just as in the case of aqueous solutions, the chemical activity of substances in non-aqueous solution is associated with their conductivity, that is, with their dissociation. Thus, while investigating the catalytic decomposition of bromcamphorcarboxylic acid in acetophenone by various bases, Creighton[24] observed, for the majority of the bases employed, that the rate of decomposition of the acid increases with the conductivity of the base in this solvent. This behavior is illustrated by Table IV, in which are given the times required for 50 per

[22] Goldschmidt, Z. physik. Chem., **91**, 46 (1916).

[23] Kraus and Bray, J. Amer. Chem. Soc. **35**, 1315 (1913).

[24] Creighton, Z. physik. Chem., **81**, 543 (1913).

cent. decomposition of the acid by equivalent quantities of the different bases, and the specific conductivities of the bases.

TABLE IV.

Base	Time required for 50 per cent. decomposition of the acid	Specific conductivity of the base in 0.5 normal solution. $\kappa \times 10^7$
Piperidine	30 minutes	5.37
Isoamylamine	33 minutes	4.80
Benzylamine	32 minutes	3.84
Tripropylamine	34 minutes	2.28
Conine	40 minutes	1.88
Triisobutylamine	42 minutes	0.73
Quinine	52 minutes	0.77
Quinidine	53 minutes	0.81
Diisobutylamine	58 minutes	0.40
Quinaldine	80 minutes	much smaller
Aniline	about 24 hours	much smaller

The Dissociating Power of the Solvent.—The numerous investigations carried out during the past fifteen years in the field of non-aqueous solutions, show conclusively that the capacity for dissociation of those substances which are recognized in water as electrolytes, also occurs more or less distinctly in other solvents. Therefore, one of the most important problems in this field of research is the determination of the nature and origin of the dissociating power of solvents. With a view to throwing light on this problem, it has been sought to determine whether any relation exists between the other physical properties of a solvent and its dissociating power.

The Dissociating Power and Viscosity of the Solvent.—The numerous investigations of Jones and his co-workers during the past ten years have shown that a relation exists between the dissociating power of a solvent and its viscosity. As early as 1904 Jones pointed out [25] that the conductivities of comparable equivalent solutions of binary electrolytes in methyl alcohol, ethyl alcohol, other alcohols of the same series, acetone, etc., are inversely proportional to the coefficients of viscosity of the solvents. In order to determine more completely the relation between the conductivity of a solution and the viscosity of the solvent, Walden [26] has studied solutions of tetraethylammonium iodide in

[25] Jones, Amer. Chem. J., **32**, 409, 521 (1904).

[26] Walden, Z. physik. Chem., **55**, 207 (1906).

about thirty solvents. His results lead to the conclusion that, for a given temperature, the product of the viscosity (η) and the equivalent conductivity at infinite dilution (Λ_0) of different solutions is a constant quantity, *e. g.*,

$$\eta_{25^\circ} \times \Lambda_0^{25^\circ} = 0.7$$

Since he found further that the temperature coefficients of fluidity and conductivity are equal, it is evident that the above product is not only independent of the nature of the solvent, but independent of temperature as well.

The Dissociating Power and the Dielectric Constant of the Solvent.—By far the most important relation so far discovered between the dissociating power of a solvent and its other physical properties, is that which exists between the dissociating power of the solvent and its dielectric constant.

A connection between the dielectric constant of a solvent and its dissociating power was first suggested, when Thomson [27] put forward the hypothesis that "if the forces which hold the molecule together are electrical in their origin, . . . these forces will be very much diminished when the molecule . . . is surrounded by a substance possessing a very large inductive capacity." On the assumption that chemical forces are electrical in their origin, Nernst [28] later pointed out that solvents possessing the greatest dielectric constants should have the greatest dissociating powers. The combined statements of Nernst and Thomson are known as the Nernst-Thomson hypothesis.

In order to determine the relation between these two properties of the solvent, Walden has made [29] a systematic study of almost every type of organic liquid, including representatives of the alcohols, aldehydes, ketones, acids, acid anhydrides, chlorides, bromides, amides, esters, nitriles, thiocyanates and nitro-compounds. To facilitate the comparison of the dissociating power of the different solvents, one solute—tetraethylammonium iodide—was employed throughout. The values of the equivalent conductivity at infinite dilution were obtained by calculation and extrapolation, and the degree of dissociation of the solute was calculated in the usual way. In the great majority of the solvents

[27] Thomson, Phil. Mag. (v), **36**, 313 (1893).

[28] Nernst, Z. physik. Chem., **13**, 535 (1894).

[29] Walden, *Ibid.*, **46**, 103 (1903); **54**, 131 (1906).

studied, Walden found that the equivalent conductivity increased with dilution, as in aqueous solution; the irregular variation in the values for a few solvents has been ascribed to interaction between the solute and the solvent. Walden's results are in agreement with the Nernst-Thomson hypothesis, and show clearly the close parallelism between the dielectric constant (D) of the solvent and its dissociating power. The greater the dielectric constant, the greater is the percentage dissociation of the solute for a given dilution. This relation is shown by the data contained in Table V.

TABLE V.

Solvent	D	Λ_0 at 25°	Percentage Dissociation v = 100	v = 1000	v = 2000
Water	81.7	112	91	98	99
Formamide	84.0	25	93	98	98
Glycollonitrile	67.9	71.5	93	98	99
Succinonitrile	57.3–61.2	35.5 (60°)	90	95	96
Citraconic anhydride	39.5	22.5	82	93	94
Nitromethane	38.2–40.4	120	78	92	93
Furfuraldehyde	36.5–39.4	50	ca 78	91	93
Lactonitrile	37.7	40	..	89	91
Acetonitrile	35.8–36.4	200	74	90	92
Methylthiocyanate	33.3–35.9	96	77	89	91
Ethylene glycol	34.5	8	78	89	..
Nitrobenzol	33.4–37.4	40	71	88	90
Methyl alcohol	32.5–37.4	124	73	88	90
Methylcyanacetate	28.8	29.5	69	84	87
Propionitrile	26.7–27.2	165	65	84	87
Ethylthiocyanate	26.5–31.2	84.5	63	83	86
Ethylcyanacetate	26.2–26.7	28.2	65	83	87
Benzonitrile	26.0	56.5	61	80	84
Epichlorhydrin	26.0	66.8	60	81	85
Acetylacetone	25.1–26.0	79	..	83	87
Ethyl alcohol	21.7–27.4	60	54	78	82
Acetone	20.7–21.9	225	50	74	80
Ethyl thiocarbamide	19.4–22.0	106	..	66	..
Acetic anhydride	17.9	76	58	79	84
Benzaldehyde	14.5–16.9	42.5	51	73	78
Phenylacetonitrile	15.0–16.7	36	46	74	79
Acetylbromide	16.2	114	47	73	78
Acetylchloride	15.5	ca 172	46	72	79
Salicylaldehyde	13.9	25	34	55	61

An interesting empirical relation yielded by Walden's data is expressed by the formula:

$$D \sqrt[3]{v} = \text{constant},$$

where D is the dielectric constant of the solvent and v is the dilution at which the degree of dissociation of tetraethylammonium iodide has a given value in a particular solvent. The high dissociating power of water agrees with its position in the table, for of all the common solvents it possesses by far the greatest dielectric constant. Formamide, which has a dielectric constant slightly greater than that of water, imitates in a remarkable manner many of the physical characteristics and constants of water. The dissociation of binary electrolytes in this solvent is even greater than in water. In this connection the high dielectric constant (95.0) of liquid hydrocyanic acid and its high dissociating power (page 4) is of interest.

Brühl[30] has pointed out that no absolute proportionality exists between the dissociating power of a solvent and its dielectric constant, nor can be expected to exist, inasmuch as the dielectric constant varies greatly with temperature and also with the frequency of the electric waves. He regards the dissociating power of a solvent to be due to a form of energy which he calls the "medial energy;" this, although not identical, is connected with the heat energy of the solvent. Since physical and chemical changes are only associated with changes in energy, the internal energy of a solvent cannot be actually measured; but it is probable that the internal energy is greatest in those solvents with the highest specific heat, and heat of evaporation or fusion. Examination of these physical constants for a large number of liquids has indicated that high values are always associated with high dielectric constants and high dissociating powers.

The Dielectric Constant and the Associating Power of the Solvent.—According to Walden,[31] the value of the dielectric constant of a liquid depends largely upon the presence of certain chemical groups. He has found that the dielectric constant is increased by the substitution of the following groups, the magni-

[30] Brühl, Z. physik. Chem., **30**, 1 (1899).
[31] Walden, *Ibid.*, **70**, 569 (1910).

tude of the increase increasing in the order from left to right: I, Br, Cl, F, NH_2, CN, CO_2H, CHO, CO, NO_2, OH. This is almost the same order in which Auwers found[32] that the substitution of these groups increased the ability of the solvent to prevent the association of the molecules of the solute. The influence of these groups upon the dielectric constant and upon the associating power of a solvent indicates that there must be some connection between these two properties. It is evident that with increasing power of dissociation there must occur not only an increase in the dissociation of the molecules into ions but also an increase in the dissociation of the polymerized molecules into simple ones.

A comparison of the values of the abnormality factor, *i.* (*i. e.,* the number of times the osmotic pressure, the freezing-point lowering, etc., of solutions is greater than the normal value), which have been obtained for non-aqueous solutions by conductivity, cryoscopic and ebullioscopic methods, often leads to contradictory results. Sometimes *i* values which are less than unity are obtained by the latter methods, even though the presence of conductivity indicates that the solute must be dissociated to a considerable extent in the solution. This anomaly may be explained, however, if we assume that in such cases the number of molecules of solute which dissociates is exceeded by the number which associates. It has been found[33] when the *i* values for tetraethylammonium iodide obtained by ebulliscopic measurements are compared with those obtained by conductivity measurements, that although they are of the same order there is by no means complete agreement. With the alcohols as solvents, the values of *i* obtained by the osmotic method are always smaller than those obtained by the conductivity method, the divergence between the two sets of values increasing with the concentration of the solute. Sometimes the same solvent possesses the power of dissociating certain solutes and associating others. For example, while formic acid dissociates potassium chloride and tetraethylammonium iodide, hydrochloric acid apparently associates to double molecules in this solvent.[34]

[32] Auwers, *Ibid.*, **42**, 513 (1903).

[33] Walden, Z. physik. Chem., **55**, 281 (1906).

[34] Zanninovich-Tessarin, Z. physik. Chem., **19**, 257 (1896).

The Dissociating Power and the Degree of Dissociation of the Solvent.—The work of Ramsay, Guye, Beckmann, and others has shown that, in general, the alcohols, phenols, aliphatic acids, aldehydes, ketones, nitriles, amides, urethanes and thiocarbimides are more or less associated in the liquid state. Further, it has been found that these liquids are usually good solvents, and that they possess dissociating power. It has been observed [35] that solutions of salts and organic acids in associated liquids possess high conductivities. Dutoit and Friderich have found [36] that the behavior of binary salts in solutions of acetone and acetonitrile is analogous to that exhibited in aqueous solution. The conductivity of these solutions increased in accordance with the dilution law, and the temperature coefficients of conductivity were normal. In the case of ternary electrolytes, however, the conductivity was found to be much lower, not exceeding one-fourth of the value obtained for binary electrolytes. In view of their own results and those of other investigators, Dutoit and Friderich conclude that when the same electrolyte is dissolved in different solvents, the values obtained for the equivalent conductivity at infinite dilution are direct functions of the degree of association of the solvent, and inverse functions of its viscosity. In contradiction to this conclusion, the results of Euler [37] show that solutions of potassium iodide in nitrobenzol, benzonitrile and furfurane exhibit considerable conductivity, and, therefore, are dissociated, even though these solvents are unassociated.

A close parallelism exists between the degree of association of a solvent and its dissociating power; and solvents which are largely associated invariably have high dielectric constants. The reverse is not true, however, for many liquids with high dielectric constants are not associated. The relation between the degree of association of a solvent and its dielectric constant is shown by the data contained in Table VI.[38]

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[35] Dutoit and Aston, Compt. rend., **125**, 240 (1897).

[36] Dutoit and Friderich, Bull. Soc.. Chim. (iii), **19**. 321 (1898).

[37] Euler, Z. physik. Chem., **28**, 619 (1899).

[38] Walden, *Ibid.*, **54**, 129 (1906).

TABLE VI.

Substance	Association factor.	Dielectric constant.
Formamide	6.18	84
Water	3.81	81.7
Formic acid	3.61	58
Acetic acid	3.62	6.3
Methyl alcohol	3.43	32.5
Glycol	2.92	34.5
Ethyl alcohol	2.74	21.7–27.4
Acetonitrile	1.67	36
Propionitrile	1.45	26.8
Acetone	1.26	21.3
Benzonitrile	0.97	26.0
Nitrobenzol	0.93	35

Liquid ammonia, which has a high dissociating power (page 3), is probably highly associated and has a high dielectric constant.[39] The influence of the degree of association of the solvent upon its dissociating power is clearly seen in the case of solutions of silver nitrate in benzonitrile and propionitrile. According to Schlundt,[40] the dissociation of this solute is markedly greater in the latter than in the former solvent. Although the dielectric constants of these solvents are almost equal, it will be observed from the values given in Table VI, that while the molecules of benzonitrile do not associate, those of propionitrile polymerize to a considerable extent. Sakhanov [41] has found that the Nernst-Thomson hypothesis only holds when the dielectric constant is not too small. When this constant is small, the dissociating power of the solvent depends solely upon its constitution and is entirely independent of the magnitude of the dielectric constant.

The Influence of Unsaturated Valences on the Dissociating Power of the Solvent.—It has been suggested that only those solvents which contain polyvalent elements with unsaturated valences possess dissociating power. Thus, the dissociating power of water and the lower alcohols is attributed to the presence of bivalent oxygen which tends to become tetravalent; that of hydrocyanic acid, hydrazine, the nitriles, etc., to the presence of trivalent nitrogen which tends to assume the pentavalent condition. However, this theory fails to explain why benzol, cyan-

[39] Brühl, Z. physik. Chem., **27**, 319 (1898).

[40] Schlundt, J. Phys. Chem., **5**, 168 (1901).

[41] Sakhanov, J. Russ. Phys. Chem. Soc., **42**, 1363.

ogen, carbon disulphide and phosphorus trichloride, all of which contain polyvalent elements with unsaturated valences, apparently have no dissociating power.

Union of Solute With Solvent.—Considerable evidence has been obtained during the past few years which points to the participation of the solvent in the process of dissociation, through a union with the solute. Recent investigation indicates that a complete knowledge of this phenomenon will probably throw a great deal of light on the nature of the dissociating power of solvents.

Theories.—It has been suggested that the process of dissociation begins when the solvent unites with the positive and negative particles of the molecules of the solute, and that as soon as all the latent atom valences are saturated, these particles are free to assume the ionic state. The electrostatic attraction between the oppositely charged particles, which tends to hold them together in the molecule, is so much smaller the greater the dielectric constant of the solvent. Thus, it is possible for oppositely charged particles or ions to exist at shorter distances apart in a solvent with a high dielectric constant than in one with a small dielectric constant. Consequently, a smaller volume of the first solvent than of the second would be required to obtain the same degree of dissociation of a solute. It is probable that it is the chief function of chemical affinity to produce the ions, and it is the function of the dielectric property of the solvent to hold the ion and its integument of solvent together, once the ion is formed. While decrease in electrostatic attraction alone would be insufficient to explain dissociation and, still less, the freedom of the ions, on the other hand, dissociation as an influence of chemical affinity is in agreement with many observed facts.

It is impossible within the scope of this paper to give all the different hypotheses that have been put forward to account for the dissociating power of solvents. In the case of each, many difficulties and contradictions are encountered. All these hypotheses fail when we pass from the general to the particular. One of the greatest difficulties at present is to explain the simultaneous occurrence of both dissociating and associating powers in the same solvent. Although it is probable that all the hypotheses put forward contain some truth, the whole truth will doubtless be forthcoming only when our knowledge regarding the unions

which occur between solvent and solute becomes more extensive. Much experimental data have still to be accumulated systematically before a general theory of the dissociating power of solvents can be established.

It is probable that the dissociating power of a solvent cannot be regarded as a well defined physical constant, but that it must be considered as a specific property of the solvent, which has its origin in the physical constants existing between solvent and solute.

Steel Conductors for House Wiring. ANON. (*Electrical Review*, vol. 69, No. 9, August 26, 1916.)—In order that the central stations of the country may widen their fields of service, there has been an insistent demand for some time for a cheaper system of electric wiring which would be applicable especially to already built houses, cottages, and flats of the most modest type. The concentric system, which has been widely applied in certain countries of Europe, has been looked to by many as a system which would meet this demand. To the disappointment of many, trial installations in this country have not indicated economies over the usual methods of wiring.

There is another method of reducing the cost of small wiring installations which has received little or no consideration in this country. Installations in small residences invariably use more copper in the conductors than is necessary from the electrical standpoint, and the high price of copper at the present time makes this item more important than it formerly was. The smallest size of wire that is permitted for either main or branch circuits is No. 14 B. & S. gauge, which has a rated capacity of 15 to 20 ampères, according to the kind of insulation with which it is provided. Wire as large as this is required for mechanical reasons, since a smaller size would be more likely to become broken and lead to trouble and possibly hazards. The carrying capacity of No. 14 wire is much more than sufficient for most branch circuits, since such circuits are limited to a connected load of 660 watts, which upon a 110-volt circuit is equivalent to six ampères. Copper is chosen as the material for conducting wires on account of its high conductivity. It is evident here that the conductivity is much higher than necessary from electrical considerations, and a cheaper material could be substituted without detriment. Such material can be made available in the form of insulated iron or soft-steel wire. Such wire would have about seven times the resistance of a copper wire of the same cross-section, and in small sizes the magnetic permeability would be of no consequence in alternating-current circuits of commercial frequencies, so far as reactance and skin effect are concerned.

SLAB DEFLECTION AND SUBSIDENCE OF COLUMN SUPPORTS IN A FLOOR TEST OF INTERNATIONAL HALL, CHICAGO, MADE SEPTEMBER, 1913.*

BY

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Reinforced concrete floor slabs are somewhat imperfectly elastic, and in testing them an allowance is commonly made for this fact by the requirement that in case of any excessive deflection at least 80 per cent. of it shall disappear within a week after the removal of the load which produced the deflection. This requirement recognizes the imperfection of the elastic properties of the slab in two ways, since first, it does not forbid some residual permanent deflection, and, further, it does not require immediate recovery, neither of which concessions could be made in case of a perfectly elastic structure.

Few materials of construction are so perfectly elastic as actually to make an immediate and complete recovery, but a much larger margin is allowed to reinforced concrete than to most other materials. It should be noticed that on account of its being a composite structure, composed partly of steel and partly of concrete, of which the steel is more nearly perfectly elastic than the concrete, a floor slab with steel massed in the column heads will have a more prompt and complete recovery than one with so-called drop heads of concrete in place of the heavy reinforcement in the column heads.

But in the retardation or time lag of slab recovery a phenomenon is exhibited which is not found to any perceptible extent in other kinds of materials of construction in ordinary use. Since recovery from slab deflection is gradual and may never be complete, and since a corresponding gradual increase of deflection must occur under a load, it has been argued by some that final stability under a load is impossible. The permanence, however, of ancient concrete structures seems to show that there must be a limit to the deformations and deflections that will take place

* Communicated by the Author.

under loads, just as there is to the recovery after removal, and it must be admitted that concrete is not really plastic, although the property of concrete to which attention has just been directed bears some of the marks of plasticity. Were concrete really plastic under ordinary stresses, that fact would spell the ultimate destruction of buildings and bridges made of that material. But concrete is a kind of artificial rock and evidently reaches, in time, a permanent and invariable state in which progressive changes no longer take place, although, in course of hardening, phenomena may occur which, if not ultimately checked, would involve final collapse.

Now the theory of the flexure of slabs differs from that of continuous beams in important particulars, one of which is that the applied moments and the observed resisting moments are not equal to each other, a fact the reasons for which are discussed elsewhere. But to this fact it is due that the economical and safe depth or thickness of slabs for any given span is small compared with that of beams, a fact which partially obviates one of the great drawbacks that exists to the use of continuous beams, viz., the large stresses introduced by any accidental subsidence of supports.

As just stated, one of the most serious practical objections to the employment of continuous beams lies in the very large stresses induced by settlement of supports, because this will usually entirely disarrange the stresses for which the structure was designed. This hazard has operated very largely to prevent the construction of continuous bridges consisting of several successive spans. But a subsidence of a magnitude which might produce dangerous stresses in a structural steel building may be taken up in course of construction in a reinforced concrete building without requiring special attention, since the relatively large flexibility of these slabs is such as to make the effects of moderate subsidences inconsiderable compared with the effects of subsidences of the same absolute amount in bridges and deep girders.

The structural utility of continuous panels is so great as to outweigh their risks and practically to necessitate their adoption. The fact previously stated that the applied moments and resisting moments in slabs are unequal does not, however, prevent us from applying the theory of flexure to slabs as well as to beams, al-

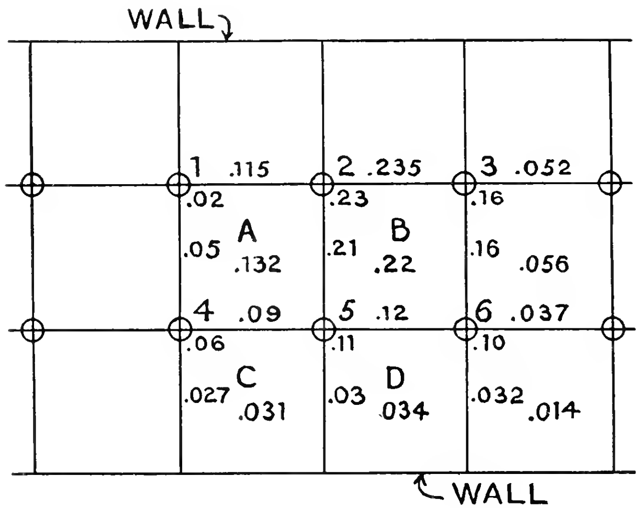
though it does prevent us from calculating the moment of inertia of the resisting materials in slabs in the same manner as in beams. But those deductions from the theory of flexure which are independent of the magnitude of the moment inertia are valid equally for beams and for slabs. Such, for example, are the relative deflections and vertical displacements of different points in the span. This it is which has made it possible to treat with success an important question which arose in the discussion of the test of the floor of International Hall.

In this floor slab the foundations of the columns proved insufficient to carry the test loads without yielding by amounts large enough to have considerable effects upon the stresses and deflections of the four loaded panels, each of which was 18 by 18 feet square. The floor as tested was a deck slab with no columns on its upper side. It was three panels wide and nine panels long, and was built into the surrounding walls of an old brick building by cutting into them somewhat for space to place steel and pour concrete, so that the edges of the slab were made integral so far as possible with the walls. The four panels which were tested formed a square near the middle of one side of the slab, two of them being in one tier of wall panels and the other two in the middle tier adjacent to them. In this floor, with its two rows of supporting columns parallel to the long sides of the building, certain vertical displacements were measured at the columns and at mid-span between columns and walls, both before and a week after the removal of the final test load, and the question was to determine whether the recovery was as much as 80 per cent. of the maximum deflection, and so whether there still remained as much as 20 per cent. of the maximum. The solution of this problem implicitly requires the determination of the magnitude of the vertical displacements which would occur in the slab by reason of the subsidences of the column supports only; for the actual vertical displacement at any point of the slab is the sum of two kinds of displacement; first, that due to the bending by reason of subsidence of the points of support, and, second, that due to bending by reason of the applied load. The fact that the subsidence of columns was itself also due to the applied load is immaterial, since the effect would be the same were the subsidence due to some other cause.

When that part of the vertical displacement at any point which is due to the subsidence of supports is subtracted from the actual vertical displacement observed at that point, the remainder is the true deflection and may be either that due to the effect of the load in bending the slab or to the residual bending effect after removing the load, according as the load is still resting upon the slab or has been removed. The ratio of the remainder after removal to the remainder before removal will show how much the recovery falls short of being complete.

Let these four panels be designated by *A, B, C, D,* respec-

FIG. 1.



tively, as shown in Fig. 1, with columns numbered from 1 to 6. Panel *B* is the centre of the entire floor. Let the reinforced direct belts extending across the slab over the columns be regarded as continuous beams fixed horizontally at the walls. The assumption that they are fixed at the walls is probably not entirely correct, but more nearly so than the assumption of mere support at the walls. It is found that the latter assumption gives results which do not differ much from those obtained by assuming the ends to be fixed in direction as well as position. If *L* be taken as the distance between successive columns, these belts or beam strips, which may be taken roughly as having a width of 0.5 *L,* are not of uniform moment of inertia throughout their lengths,

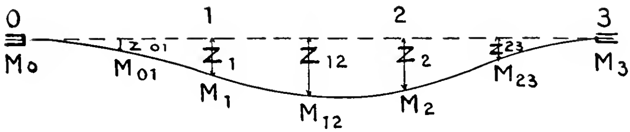
but will, for the purpose of preliminary investigation, be assumed as uniform, and their irregularity of cross-section will be allowed for later.

Given a uniform continuous beam of three equal spans, each of length L, as shown in Fig. 2, whose extremities are fixed horizontally on the same level, but whose intermediate points of support at points 1 and 2 are depressed by the observed subsidence z_1 and z_2, respectively, below the level of the extremities, to find the displacements z_{12}, z_{01}, z_{23}, at the middle of the centre and end spans respectively, there being no stresses or displacements due to any other cause than the subsidences z_1 and z_2.

Let M_0 and M_3 be the moments at the extremities and M_1 and M_2 at the intermediate supports, respectively.

Then, by making use of the theorem of three moments, which applies in its general form to any two successive spans of a straight beam with supports at any arbitrary levels, we have the

FIG. 2.



following four equations by taking four successive pairs of spans, as follows: The first pair, Equation (1), consists of a span of zero length and a span extending from the wall at 0 to the first row of columns at 1. The effect of a span of zero length is to give the slab a fixed horizontal direction at the wall. The second pair of spans, Equation (2), extends from the wall at 0 to the first row of columns and from the first to the second row of columns at 2. The third pair, Equation (3), extends from the first row of columns at 1, across the second row to the other wall at 3, and the fourth pair, Equation (4), from the second row of columns at 2, to the second wall at 3, and includes a span of zero length at that wall.

The notation may be understood from Fig. 2, in which the tangents at the 0 and 3 are fixed in a horizontal position and the vertical displacements or subsidences at the intermediate supports 1 and 2 are of known amounts, z_1 and z_2, and the vertical displacements at mid-span are designated by z_{01}, z_{12}, and z_{23},

respectively, while the applied bending moments are denoted by the letter M with corresponding subscripts, and the length of the equal spans between supports by L.

$$6\,EIz_1 = (2M_0 + M_1)L^2 \quad \text{(1)}$$

$$-6\,EI(2z_1 - z_2) = (M_0 + 4M_1 + M_2)L^2 \quad \text{(2)}$$

$$6\,EI(z_1 - 2z_2) = (M_1 + 4M_2 + M_3)L^2 \quad \text{(3)}$$

$$6\,EIz_2 = (M_2 + 2M_3)L^2 \quad \text{(4)}$$

Considering now the mid-displacement z_{12} of the middle span 12, it may be expressed in terms of the two end moments and end displacements of that span as follows:

$$6\,EI(z_1 + z_2 - 2z_{12}) = 3/4(M_1 + M_2)L^2 \quad \text{(5)}$$

as appears from the fundamental equation of moments and shears used in establishing the equation of three moments.

The solution of these five simultaneous linear equations by the method of indeterminate multipliers or otherwise gives as a result

$$z_{12} = 5/8(z_1 + z_2) \quad \text{(6)}$$

A similar consideration of the mid-displacement z_{23} of the end span 23 shows that

$$6\,EIz_{23} = 1/8(M_2 + 5M_3)L^2 \quad \text{(7)}$$

The solution of the first four simultaneous linear equations and (7) gives

$$z_{23} = (19z_2 - 4z_1)/40 \quad \text{(8)}$$

and by symmetry

$$z_{01} = (19z_1 - 4z_2)/40 \quad \text{(9)}$$

Hence

$$z_{01} + z_{12} + z_{23} = z_1 + z_2 \quad \text{(10)}$$

which is a fundamental equation of displacements in this case of no loads.

In case the assumption were that the walls are simple supports and exert no restraint, the values of the displacements at mid-span have been found to be

$$\left.\begin{aligned} z_{12} &= 23(z_1 + z_2)/40 \\ z_{23} &= (29z_2 - 6z_1)/40 \\ z_{01} &= (29z_1 - 6z_2)/40 \end{aligned}\right\} \quad \text{(11)}$$

from which it appears that this would make the displacement at mid-span of the middle span a little less and at mid-span of the

end spans a little greater than when the ends are fixed, and the same kind of effect, but of smaller amount, will be produced by any relaxation of fixity at the walls.

It will be noticed from (11) that

$$z_{12} = z_{01} + z_{23}$$

It is evident that the floor under consideration may be taken to consist of beam strips not only crosswise from side wall to side wall, as has just been done, but also as made up of beam strips parallel to the side walls and extending lengthwise of the building, and that the agreement of the results of computations by these two methods will tend to establish their correctness. Suppose the beam strips to each have a width of $\frac{1}{2}L$ extending over the two rows of columns parallel to the long side walls, with a strip of the same width lying between these two. If the length of these strips be taken as $4L$, they may be assumed to have their ends practically fixed horizontally, with certain observed vertical displacements at the three intervening columns. The problem in this case is this: Given the vertical displacements z_1, z_2, and z_3 at points of support 1, 2, and 3 of a beam fixed horizontally at the ends 0 and 4, to find the vertical displacements z_{01}, z_{12}, z_{23}, and z_{34}, at mid-span between each pair of supports. The equations are like those already used in the case of three spans, and the values arrived at in the same manner are:

$$\left.\begin{aligned} z_{01} &= (106z_1 - 21z_2 + 6z_3)/224 \\ z_{12} &= (142z_1 + 133z_2 - 30z_3)/224 \\ z_{23} &= (142z_3 + 133z_2 - 30z_1)/224 \\ z_{34} &= (106z_3 - 21z_2 + 6z_1)/224 \end{aligned}\right\} \qquad (12)$$

It will be noticed that in this case

$$z_{01} + z_{12} + z_{23} + z_{34} = z_1 + z_2 + z_3 \qquad (13)$$

which is an equation of deflections for four spans similar to (10) for three spans.

On Fig. 1, which shows a plan of the panels of the test, are inscribed, at columns 1 to 6, the amounts of the vertical displacements observed under the final load in inches, and at mid-span between these columns the vertical displacements, computed according to the foregoing equations, that would take place in a uniform slab by reason of the displacements at the columns without applying any load to the slab except the reactions at the

columns which are necessary to produce the displacements at the columns.

Displacements at panel centres are also given. These last are computed both by taking beam strips crosswise and lengthwise of the floor midway between the beam strips already computed across the tops of the columns. Practically the same values at panel centres are obtained from the computation by strips crosswise as lengthwise. This affords a satisfactory check on the work. Were the slab of uniform moment of inertia throughout, the displacements which have been computed at mid-spans and panel centres would express the position of the surface from which true deflections should be measured, or the surface of zero deflection from which deflections due to the load or lack of recovery are to be measured. That however, is not entirely correct for a floor slab, by reason of the great relative stiffness and extent of the column heads, which must be allowed for. The side belts are weaker near mid-span than elsewhere. The kind of effect that this produces may be made evident by considering what would be the effect of joints at mid-span of the beam strips across the floor. That would cause angles in the strips at each mid-span with comparatively straight portions over the columns. At mid-span in the centre of the strip the displacement would evidently be increased by such joints or by any weakness of this kind. In the case of the test under consideration it is estimated that the combination of a central conduit in each panel tier parallel to the long side walls, with the lack of columns integral with the slab above it, added not less than 25 per cent. to the computed vertical displacements at the centres of panels *A* and *B* and midway between those points, these being the points of maximum deflection at which the percentage of recovery is to be determined.

The accompanying table gives in column 1 the computed vertical displacements at these points, and in column 2 these amounts increased by 25 per cent., to take account of the increased displacement by reason of lack of uniformity in the slab. Column 3 gives the observed displacements under maximum load, and column 4 the observed displacement after removal of the load and recovery. Column 5 is the difference between column 3 and column 2, or the deflection under the load. Column 6 is the difference between column 4 and column 2, or the deflection

after removal of load and recovery. Column 7 is the ratio of column 6 to column 5, or the percentage which which the residual deflection is of the maximum. Column 8 is 100 per cent. less the per cent. in column 7, or the percentage of recovery, which has a mean value of 80.7.

TABLE OF VERTICAL DISPLACEMENTS AND DEFLECTIONS IN INCHES.

	1	2	3	4	5	6	7	8
At centre of	Computed for uniform slab	Increased 25 per cent. not uniform	Maximum observed displacement	Minimum observed displacement	Maximum deflection column 3 less column 2	Minimum deflection column 4 less column 2	Percentage of residual deflection	Percentage of recovery
Panel *A*...	0.13	0.16	1.04	0.38	0.88	0.22	25	75
Span 2–5..	.21	.25	.95	.37	.70	.12	17	85
Panel *B*...	.22	.264	.98	.38	.716	.116	16	84
Mean...	0.19	0.225	0.99	0.38	0.765	0.152	19.3	80.7

The application of a rule requiring a recovery of 80 per cent. in this case, however, discriminates against the floor structure and attempts to have it make good the shortcomings of the faulty foundations on which the columns rest. At the time of the maximum load, when subsidence of the columns took place, the columns were subjected to a very considerable bending moment by reason of the tipping of the floor, which was integral with the column heads. This caused the foundation of each column not only to sink vertically, but to tilt at the same time in an inelastic displacement. On removal of the load, any restoration of the foundation either to its original vertical position or level would have to be accomplished, not by any elastic effort of the foundation itself, but by an elastic effort coming from the floor itself. Not only was work required to displace the foundation at first, but additional work will be required after the removal of the load to right the foundation, or else the foundation will itself tend to restrain the slab and hold it in its displaced position not merely by reason of its vertical displacement, but by reason of its tilted position in addition to that. Thus it is that the displaced foundations tend to prevent the recovery of the slab in other ways than merely by the vertical displacements which have been considered in the preceding computations.

Rocks Made to Tell Their Own Story. ANON. (*United States Geological Survey Press Bulletin*, No. 286, September, 1916.)—The walls of the Grand Canyon in Arizona form a great natural geologic section, in which each layer of rock is in its original position relative to those above and below it. In few other places, however, is the story of the upbuilding of the earth's crust so plainly and impressively told. As a rule, the geologist who would decipher the records of the rocks must get a bit here and a bit there. He may find the edges of some beds exposed in a river bluff and others sticking out on a steep mountain side. He determines by fossils or other means the order in which the beds were deposited, and by putting all his information together he constructs what he calls a columnar section for the district in which he is working—that is, a section showing the order, thickness, and character of the beds. Such a section discloses the strata that form the upper part of the earth's crust at that place, just as a slice of layer cake shows at a glance the various layers of which it is composed.

After a number of districts in a region have been studied and their general columnar sections determined, the geologic history of the region can be learned by comparing these sections, just as the engineer who is drilling for low-grade copper ores compares his drill records and thus learns the outlines of the ore body. Such a comparison of the beds at one place and another shows how certain beds change in character and thickness from place to place or even thin out and disappear. It enables the geologist to draw some conclusions as to the former distribution of land and sea, to distinguish the deposits laid down in deep water from those spread by rivers over their flood plains, and to reconstruct in imagination the course of events at a time long before the beginning of the Grand Canyon. Such a comparison has recently been made for Arizona and is published by the United States Geological Survey, Department of the Interior, as Professional Paper 98-K, by F. L. Ransome, geologist. The report is obtainable on request from the Director.

Semi-steel. D. McLAIN. (*Proceedings of the American Foundrymen's Association*, September 11–15, 1916.)—Semi-steel, although not recognized in iron and steel nomenclature, ranks among the most valuable products of the gray iron foundry. More than 100,000 pounds were produced last year to meet the demand for stronger metal and lighter sections. Semi-steel is made in the same cupola with regular gray iron mixtures. No extra coke, special appliances, fluxes or new equipment are necessary. It is made in the same heat with other mixtures. It may be melted in the early part of a heat, in the middle, or in the last part of a regular heat. It may begin with 30 to 40 per cent. steel on the bed and then follow with 20 to 25 per cent. steel. The product is 25 to 60 per cent. stronger than gray iron, thus permitting a large reduction in weight.

STRESSES IN IMPACT.*

BY

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THE physical laws of most value in the study of the phenomenon of impact are the laws of conservation of momentum and conservation of energy. By means of the principles expressed by these laws the velocities of two colliding bodies after impact may be determined for all conditions, such as elastic, semi-elastic, and "dead" impact; and the energy lost may be computed when the physical properties of the material are known. Stresses due to suddenly applied loads may also be obtained, with the aid of certain assumptions, when the elastic limit of the material has not been exceeded. In case the elastic limit of the material has been exceeded theory casts little light upon the actual stresses or even approximate stresses such as the modulus of rupture or the stress at failure, which is of so much importance in engineering construction. How do the stresses at failure of a wooden beam, for example, compare with the corresponding stresses for a beam loaded statically to rupture? Will a material absorb more or less work to the point of failure when suddenly loaded than it does for slow loading? Is the modulus of elasticity the same for the two methods of loading? Will a beam deflect farther at rupture in impact than it does in static bending? While the latter question may be readily answered by making a few simple tests, the matter of stresses is not so readily put aside and requires for its solution both the application of the laws of impact and experimental data of a somewhat unique nature. It was primarily the determination of the stresses actually set up in impact that prompted the investigations presented herewith.

Before proceeding to the tests themselves it will be necessary to analyze the phenomena of impact and to formulate the theory involved. In the study of the theory the conditions under which the tests were made will be kept in mind constantly and no assumptions will be made that cannot be amply justified by the results of the test.

* Communicated by the author.

For the purpose of this study we will imagine the usual wooden beam supported at the ends and struck at the centre by a falling weight or tup whose mass is at least ten times that of the beam. The beam is rectangular in section, and the nose or surface of contact of the tup is rounded so that undue crushing of the fibres on top of the beam will be avoided. The tup is allowed to fall from a height sufficiently great to break the beam with a single blow. At the instant of contact the pressure between the tup and the beam is zero. Then, as the tup proceeds in its descent, dropping through a distance ΔS, there results, first, a slight depression or indentation in the beam due to the inertia of the particles of the beam in the path of the motion; second, a displacement of the centre of gravity of the section of the beam under the tup equal to ΔY, so that the difference ΔS-ΔY represents the depth of the indentation; and, third, a wave is sent out to each side with a speed equal to that of the velocity of stress propagations in timber. Inasmuch as ΔY is small, the upward pressure of the beam due to flexure is as yet quite negligible, and the actual pressure between the beam and the tup may be considered as due entirely to the inertia of the particles in the vicinity of the centre. As the descent proceeds with ΔS still very small, the difference ΔS-ΔY becomes constant, and soon the centre of gravity of the section under the tup has the same velocity as the tup itself. This does not imply, however, that the sections to either side of the centre have attained velocities proportional to their proximity to the centre or to the deflections associated with a deflection ΔY at the centre, due to static loading. The latter state is merely the limiting or equilibrium condition that the beam assumes as the deflection proceeds. Since the velocity of stress propagation for timber is about 13,000 feet per second, and the total time for the deflection has a minimum value of 0.02 second for the tests made on 50-inch beams, it may be assumed that this condition of equilibrium has been reached a relatively long time before the maximum deflection has been attained. When this condition has been arrived at the beam has an elastic curve very nearly the same as the elastic curve in static bending, and the pressure between the beam and the tup is due solely to flexure. In the meantime, since the bending has increased, the actual pressure between the two has also materially increased, with a corresponding increase in the depression.

Having followed the changes that take place in the beam up

to the instant that its inertia has been entirely overcome, we are now in a position to determine the external moments that set up the stresses producing failure.

Considering the forces acting on the tup, there is, first, the force of gravity giving it a downward acceleration g, and, second, an upward force p, the pressure of the beam imparting acceleration in the direction opposite to motion and equal to a. If s stands for the vertical displacement of the tup then $\frac{d^2s}{dt^2}$ represents the rate at which the tup is changing its velocity; that is, the acceleration of the tup, which, it has just been seen, is the resultant of a upward and g downward. Since the motion of the tup relative to the centre of the beam is extremely small, being due only to a change in the indentation, $\frac{d^2s}{dt^2}$ is also the acceleration of the centre beam. Besides these major forces, there remain, of course, friction of the tup in its guides and air resistance. Tests made to find the change in velocity due to friction showed that the velocity was not decreased more than 2 per cent., indicating that friction is quite small when compared to the force of gravity and absolutely negligible when compared with the upward force of the beam.

Put as an equation, these conditions are expressed by the relation

$$\frac{ds^2}{dt^2} = a - g$$

or

$$a = g + \frac{d^2s}{dt^2}$$

If p represents the pressure exerted by the beam upward in pounds, W_t the weight of the tup in pounds, and a and g accelerations in feet per second we have

$$p = \frac{W_t}{g}\,a = W_t + \frac{W_t}{g}\frac{d^2s}{dt^2} \qquad (1)$$

Proceeding now to the energy-work relations, we obtain the general energy equation:

$$\int (ds - dy)p + \int F dy + \int \frac{W_b}{2g}\,u^2 + \tfrac{1}{2}\,\frac{W_t}{g}\,v^2 + E_e$$

$$= \int W_t\,ds + \int \delta W_b z + \tfrac{1}{2}\,\frac{W_t}{g}\,v_t^2 \qquad (2)$$

Work done up to any instant plus kinetic energy at that instant is equal to the initial kinetic energy plus work available.

$\int (ds-dy)p=$ work done in compressing the fibres at the point of contact of the tup, s being distance passed through by the tup, y the distance the centre of gravity of the beam passes through, and p the pressure between the tup and the beam. The difference between y and s is usually less than ½ of 1 per cent. of the total deflection, so that the work lost in denting the beam is negligibly small and will be neglected in the subsequent discussion.

$\int Fdy =$ work done in deflecting the beam. The force F is practically identical with the pressure p, and would be exactly the same as p for weightless beams. F is in the determination of this force that the main problem of stresses in beams subject to impact lies. F is equivalent to the centre load in a static bending test, which, when plotted against deflections, gives a curve from which the modulus of elasticity, the modulus of rupture, and the energy of rupture may be computed.

$\int \frac{\delta W_b}{2g} \mu^2 =$ kinetic energy of the beam, where W_b is the weight of the beam and μ the velocity of any element δW_b.[1]

$\frac{1}{2} \frac{W_t}{g} v^2 =$ kinetic energy of the tup at any instant under consideration after initial contact, W_t being the weight of the tup.

$E_e=$ energy lost in vibrations. In all impact some energy is lost in vibrations, but this can be largely reduced by making the ratio of the weight of the machine frame to that of the tup relatively large[2]. It will be omitted on this basis.

$\int W_t ds =$ work done by gravity on the tup after initial contact with the beam.

$\int \delta W_b z =$ work done by gravity on the beam after initial contact, z being the deflection of the element δW_b.

$\frac{1}{2} \frac{W_t}{g} v_t^2 =$ kinetic energy of the tup at the instant of contact, v_t being the velocity of the tup at that instant.

While equation (2) is general and applies at any instant dur-

[1] Merriman's "Mechanics of Materials," p. 335.

[2] See article on the "Theory of Impact," by Harry D. Tieman, in the JOURNAL OF THE FRANKLIN INSTITUTE, vol. 168, p. 244.

ing the motion, the energy that exists as vibrations will be relatively large for the first part of the deflection during the time required to overcome the inertia of the beam. Consequently the subsequent discussion will concern the motion after the vibrationless condition has been more nearly reached.

Referring again to the integral $\int Fdy$, it will now be observed that the work of deflection is equal to the change in kinetic energy of the tup plus the work done by gravity on the tup and beam during deflection, minus the energy lost in imparting velocity to the beam and denting it at the point of contact.

Bearing in mind that v is the velocity at the centre after the inertia of the beam has been entirely overcome, and u is the corresponding velocity of any element δW_b, away from the centre, it is a simple matter to express u in terms of v, since the elastic curve is assumed to be known. Let l be the length of the beam, y' and z', y'' and z'' be the corresponding deflections at the centre and at any section distant x from the end, respectively, and let P' and P'' be the loads at the centre corresponding to y' and y''. Since the load at the centre is directly proportional to the deflection at the centre, or at any other point with the elastic limit

$$\frac{y'}{y''} = \frac{P'}{P''} = \frac{z'}{z''}$$

$$\frac{y''-y'}{y'} = \frac{z''-z'}{z'}$$

But $y'' - y' = dy$, and $z'' - z' = dz$, hence

$$\frac{dy}{y'} = \frac{dz}{z'}$$

$$\frac{dy}{dt}\,\frac{1}{y'} = \frac{dz}{dt}\,\frac{1}{z'}$$

$$\text{or} \quad \frac{v}{y'} = \frac{u}{z'} \qquad \text{and } u = v\,\frac{z'}{y'}$$

The deflection at any section distant x from the left end of the beam is

$$z' = \frac{P'}{48EI}\,(3l^2x - 4x^3)$$

The deflection at the centre for the same load P' is

$$y' = \frac{P'l^3}{48EI}$$

It follows that

$$u = v\frac{(3l^2x - 4x^3)}{l^3}$$

We are now in a position to evaluate two of the integrals.

$$\int \frac{\delta W_b}{2g}u^2 = \frac{W_b v^2}{gl^7}\int_0^{\frac{l}{2}}(3l^2x - 4x^3)^2dx$$

$$= \frac{17}{35}\frac{W_b}{2g}v^2$$

Also

$$\int \delta W_b z = \frac{2 W_b P}{48 EIl}\int_o^{\frac{l}{2}} 3l^2x - 4x^3)dx$$

$$= \frac{5}{8}W_b y \qquad \text{since } \frac{1}{48}\frac{Pl^3}{EI} = y$$

Inasmuch as the average weight of the beam is only four pounds and the work done by gravity in deflecting it is only $\frac{5}{8} \times 4 \times y$, while the work done by the descending tup will average $800y$, the error introduced by omitting this integral is also very small. Moreover, since one of the purposes of the discussions is to make a comparison between the energy of rupture for static and impact bending, and the former test disregards the work done by gravity on the beam, it will also be neglected here.

There results, then, upon replacing in equation (2) the integrals valuated, the new equation

$$\int Fdy + \frac{17}{35}\frac{W_b}{2g}v^2 + \frac{1}{2}\frac{W_t}{g}v^2 = W_t y + \frac{1}{2}\frac{W_t}{g}v_t^2$$

For any one height of drop v_t is a constant, hence on differentiating

$$F\frac{dy}{dt} + \left(W_t + \frac{17}{35}W_b\right)\frac{v}{g}\frac{dv}{dt} = W_t\frac{dy}{dt}$$

But

$$\frac{dy}{dt} = v' \quad \text{and } \frac{dv}{dt} = \frac{d^2y}{dt^2} = \frac{d^2s}{dt^2}, \text{ so that}$$

$$Fv + \left(W_t + \frac{17}{35}W_b\right)\frac{v}{g}\frac{d^2s}{dt} = W_t v$$

$$F = W_t - \left(W_t + \frac{17}{35}W_b\right)\frac{1}{g}\frac{d^2s}{dt^2} \tag{3}$$

From the last equation it is seen that the beam must exert a force upward that will overcome the weight of the tup and impart to a mass of $\left(W_t + \frac{17}{35} W_t\right)$ pounds an acceleration $\frac{d^2s}{dt^2}$.

The latter should be noted in particular, for it shows that the beam impart an acceleration not only to the tup but to forces in the beam also. This is obvious when one remembers that at the instant when the inertia of the beam has been overcome, which happens very soon after initial contact, the beam has acquired a considerable velocity, and this velocity is reduced to almost zero at the time of maximum deflection. These forces proceed, of course, from the elastic deformation of the fibres.

The force F being a centre force acting on a simple beam supported at the ends, the external or bending moment is obtained immediately, and equating to the internal or resisting moment there results

$$\frac{Fl}{4} = \frac{SI}{v} \qquad \text{(Within the elastic limit)}$$

or

$$S = \frac{Flv}{4I} \qquad (4)$$

Where S = fibre stress desired,

$\frac{I}{v}$ = section modulus of the beam,

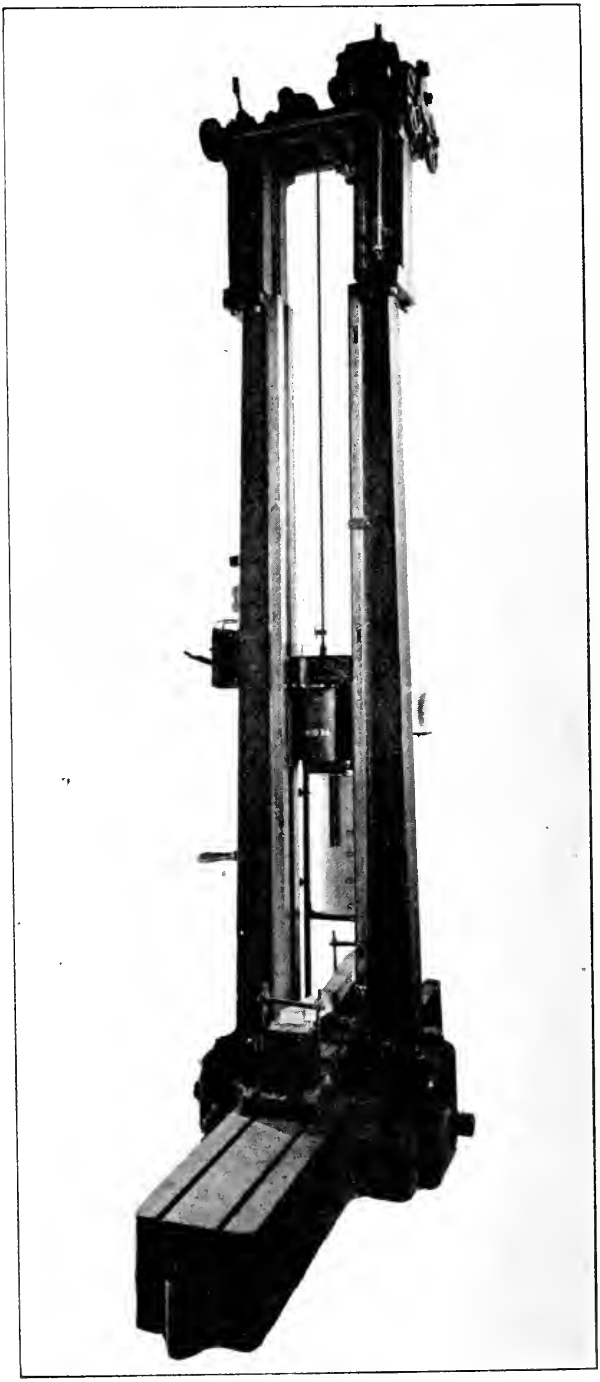
l = length of the beam.

The problem has now resolved itself down to finding the value of F in equation (4), all the other terms of the equation being known. This in turn takes us back to equation (3), in which all the terms are known except the acceleration $\frac{d^2s}{dt^2}$.
A double differentiation of the deflection-time curve yields the acceleration.

The machine used for making the tests was the Hatt-Turner drop testing machine,[3] having a maximum capacity of 72-inch drop, in use by the United States Forest Products Laboratory at Madison, Wis. It is provided with a cylinder, shown mounted in position in Fig. 1, which is rotated at a relatively high speed and has wound around its surface a metalized sheet for receiving the

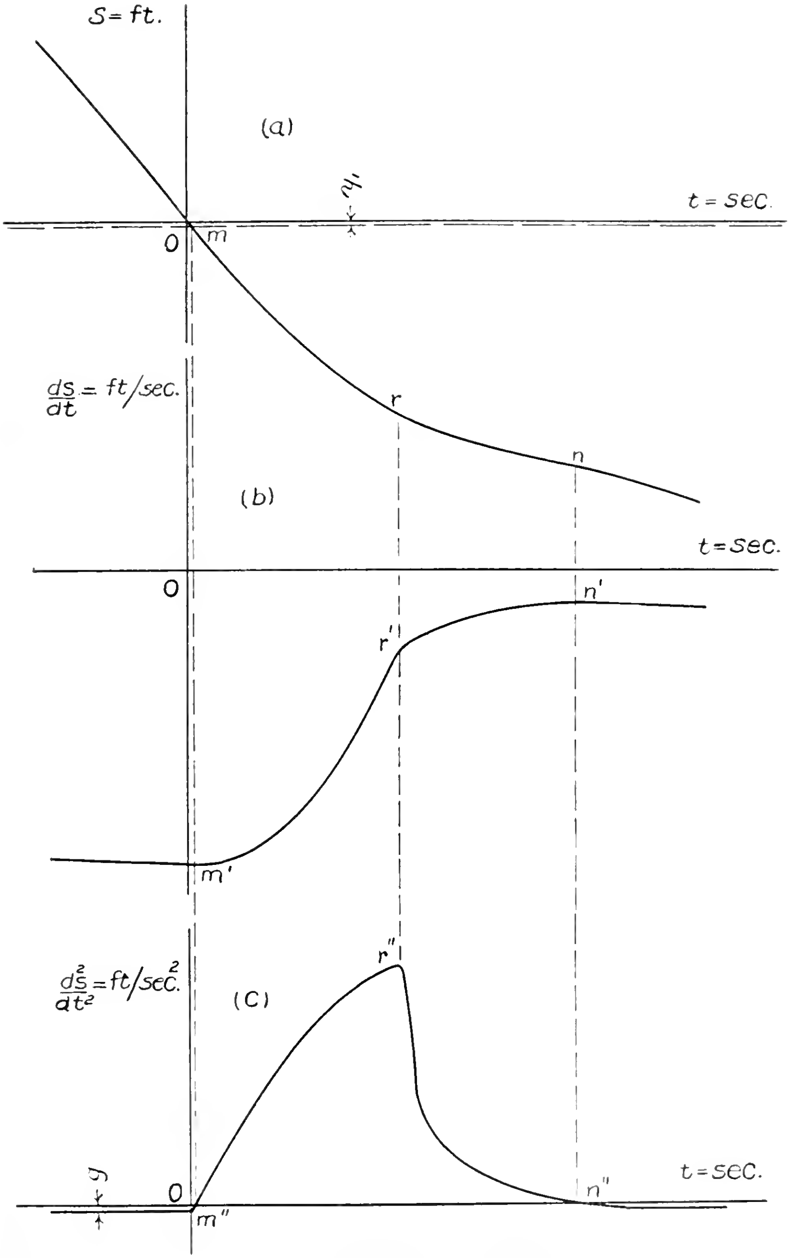
[3] A. S. T. M. Proceedings, vol. 6, p. 462.

FIG. 1.



Hatt-Turner drop impact testing machine

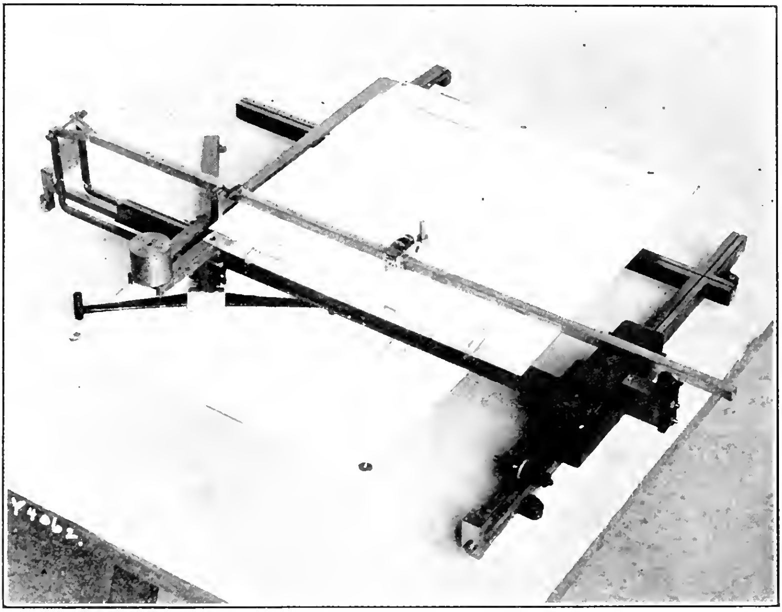
FIG. 2



A typical time-deflection curve from impact test on a timber beam, and its first and second differential curves.

impression of the stylus fixed to the descending tup. A zero or base line is first drawn on the sheet, giving the position of the tup when it rests upon the beam as a static load. An electric contact releases the tup when it has been drawn up the desired height, and a tuning-fork record gives the scale of the abscissa in seconds per inch. The latter record was taken to serve as a check on the theoretical velocity attained by the tup at the instant of striking.

FIG. 3.



The author's differentiating machine.

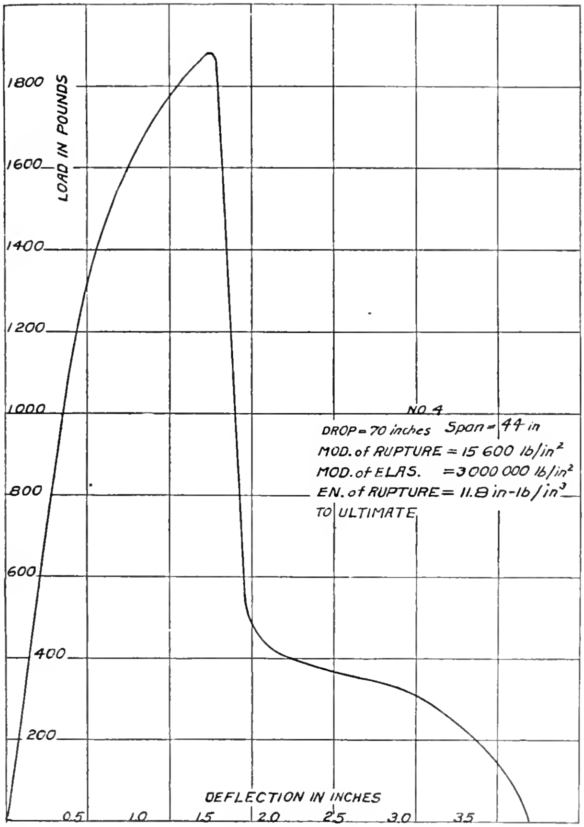
Deflections must be measured from a base line of no load, so that it was necessary to compute first the distance up from the line drawn with the tup resting on the beam to the position of no deflection, by the equation

$$y_1 = \frac{1}{48} \cdot \frac{W_t l^3}{EI}$$

A typical deflection-time curve as obtained in the tests is shown in Fig. 2 (a). The differential or velocity curve of (a) is shown as (b) immediately below, and the second differential

or acceleration curve is shown at (c). The dashed horizontal line represents the base line drawn on the paper while mounted on the cylinder with the tup resting on the beam, and y_1 is the static-load deflection computed according to the method mentioned. Deflections are likewise distances of descent, s, of the

FIG. 4.

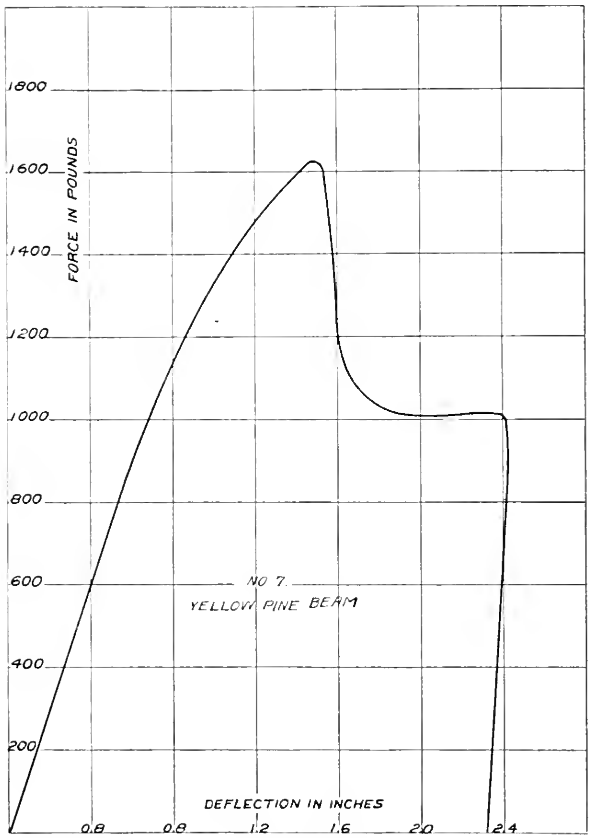


Impact force-deflection curve for a long-leaf yellow pine beam completely ruptured by a single blow.

tup, except at the start when the inertia of the beam has not been overcome. Up to the point where the curve crosses the time axis, the tup is falling freely under the influence of gravity, the velocity increasing in the downward direction proportional to the time, and the acceleration remaining constant, being equal to g, the

acceleration of gravity. At m (neglecting inertia at the beam) the curvature changes, indicating a change in direction of the acceleration from negative to positive values. At r failure occurs and the acceleration curve shows a sudden drop. Rupture is not yet complete, but proceeds up to the point n. Here again there is

FIG. 5.



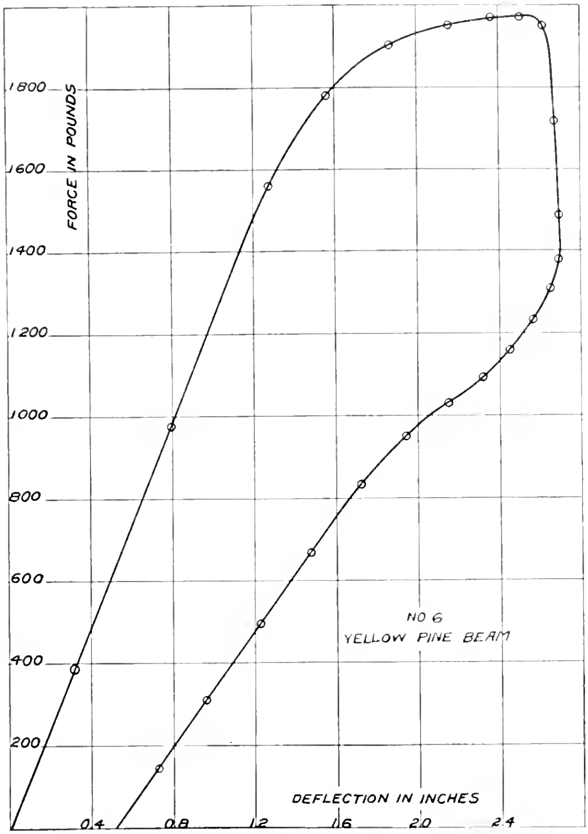
Impact force-deflection curve for a long-leaf yellow pine beam fractured but not entirely ruptured.

a change in curvature of the space-time curve, signifying a change in the direction of the acceleration, which again becomes negative; and thereafter the body falls through the action of gravity alone.

Accelerations being the quantities desired, it is necessary to go through this process of differentiation for each curve, draw-

ing first the velocity-time curve and then its differential by finding the slopes at a series of points on each curve, and plotting these slopes as ordinates to a new base line. This was done mechanically by means of the author's differentiating machine shown in Fig. 3.[4]

FIG. 6.



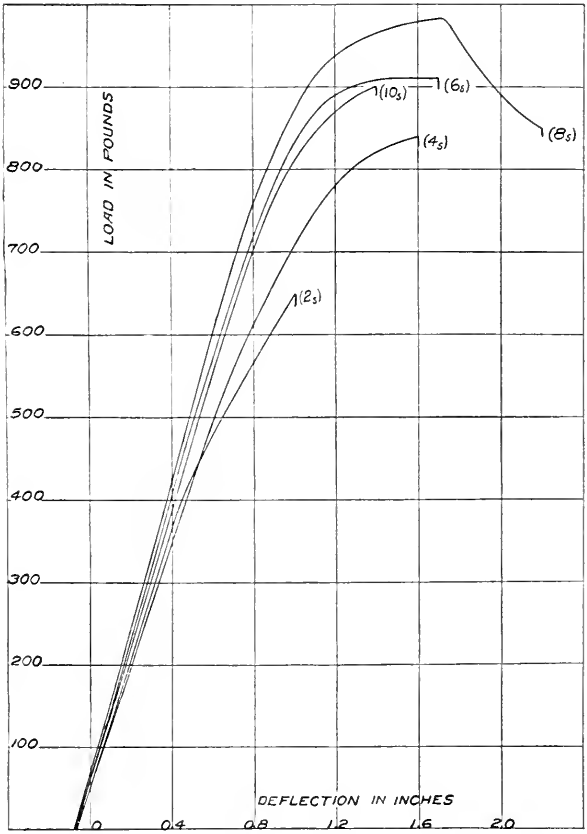
Impact force-deflection curve for a long-leaf yellow pine beam fractured but retaining considerable resilience. The circles space off equal time-intervals.

After computing the scales of each of the curves, we are in a position to draw the load or force-deflection curves for impact. By dividing the time axis into small units, finding the acceleration corresponding to each time interval, substituting in equation (3)

[4] For a description of the differentiator, refer to *Scientific American Supplement,* Feb. 12, 1916, or *The American Mathematical Monthly,* October, 1916.

to get the effective centre force F, and then scaling the deflections corresponding to each of these accelerations (hence forces), and plotting these values of force and deflection on coördinate axes, we have the desired force-deflection curve. A typical curve obtained in this manner is shown in Fig. 4. The beam was thor-

FIG. 7.



Load-deflection curves for Douglas fir beams in static cross-bending.

oughly air-dried long-leaf pine of a 2 x 2-inch section and span of 44 inches. The point of failure, as will be noted, is very pronounced, followed by continued deflection, in which the fibres that were not completely ruptured at the first failure are torn or crushed progressively.

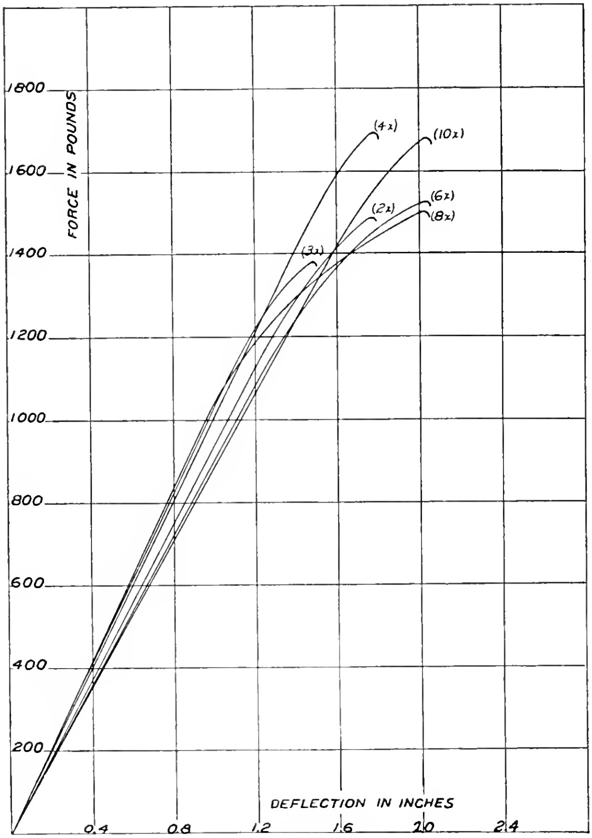
Figs. 5 and 6 show the curves for two beams not completely

ruptured, each retaining sufficient resiliency to send the tup back after the maximum deflection had been reached. The beam of Fig. 5 is peculiar in that initial failure was followed by an increase of deflection in which the load remained practically constant, indicating that the fibres failed at a rate just sufficient to balance the increase in force due to increase in deflection. At maximum deflection the total available energy had been consumed, and almost simultaneously there occurred a second failure. But the tup had already reversed its motion, as indicated by the returning curve. The latter phenomenon occurred more strikingly in the beam whose curve is shown in Fig. 6. The circles distributed along this curve are spaced at equal time intervals apart. Evidently, as the time increases, the stresses in the fibres tend to give away, causing the curve to bend over during the latter part of the sweep up to the ultimate. Motion is extremely rapid, the time between two successive points being only 0.00167 second. The values of stress at the ultimate, the so-called modulus of rupture, computed according to the flexure formula, the modulus of elasticity, the energy consumed up to the ultimate, and the deflection to the ultimate are all tabulated in the summary of results on page 788. The stresses found range from 10,000 lb./in.^{2} to 22,000 lb./in.^{2}, values considerably in excess of those of ordinary cross-bending tests. The difference in moduli of elasticity is not quite so pronounced. The large values for stress may be due in part to selected material, but more probably to the nature of the loading itself.

For the purpose of a more reliable comparison between impact and static stresses, a heavy board of Douglas fir of uniform grain was selected and cut into strips for beams so that every alternate beam was tested in impact and those between in cross-bending. Fig. 7 shows the load-deflection curves for the five beams tested in ordinary static cross-bending. Fig. 8 shows the groups of six impact force-deflection curves, each of which was obtained by going through the entire process described. The curve after the ultimate had been passed was omitted in grouping them in order to avoid confusion. Bearing in mind that each curve was developed independently, without any knowledge of the scale to which the previous ones were graphed, since the scales were not computed until all the differentiation had been completed, it is rather a remarkable fact that the curves lie so close

together and their ultimates are so nearly equal. The results for Douglas fir are summarized in the composite curves of Fig. 9, and for comparison the values are tabulated in Table II. From this it will be seen that the stresses set up in impact and the energy

FIG. 8.



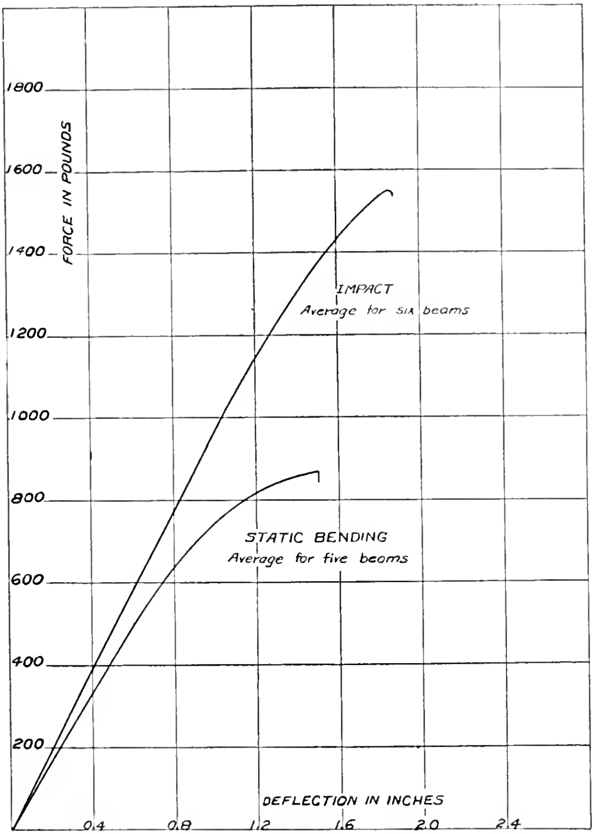
Impact force-deflection curve for Douglas fir beams ruptured by a single blow. Curves shown up to ultimate load only.

consumed are almost double the corresponding values in static bending.

To test for losses of energy the areas under the load deflection curves were each obtained with a planimeter. For the beams not completely ruptured,—that is, in which the tup came to a standstill, and may possibly even have been returned,—the work consumed by the beam to the maximum deflection is the area under the

load-deflection curve in foot-pounds. This must equal the total energy available (neglecting loss due to vibration and crushing of fibres); that is, the initial kinetic energy of the tup plus the work done by gravity on the tup during the deflection. Similarly, the area under the load-deflection curve for those beams that were

FIG. 9.



Composite load and force-deflection curves for Douglas fir.

completely ruptured is the energy consumed and is equal to the difference between the kinetic energy on initial contact and the energy at rupture, plus the work done by gravity during the deflection. The results of this comparison are tabulated in Table III, the negative sign indicating that the area under the curve was greater than the total work available, which is clearly impossible,

showing a slight inaccuracy in the work of differentiation or measurement. The average of all the differences is a little less than 1 per cent. This difference is well within the limits of accuracy of the differentiation, although it may also be accounted for by the energy lost in crushing the fibres. Probably the most significant conclusion that can be drawn from this low average error is the fact that the losses due to vibrations, hitherto unknown and sometimes assumed to be as high as 25 per cent. of the energy available, are practically zero.

SUMMARY.

1. Fibre deformations in impact set up forces which overcome the kinetic energy of the tup and the kinetic energy acquired by the beam during the short impulse period immediately after initial contact.

2. By setting up a general energy-work equation for impact, differentiating, and dividing by the velocity, an expression for the effective force was obtained:

$$F = W_t + \left(W_t + \frac{17}{35} W_b\right) \frac{1}{g} \frac{d^2s}{dt^2}$$

3. Double differentiation of the time-deflection curve obtained autographically yielded the acceleration-time curve.

4. By substituting values of the acceleration from the acceleration-time curve in the equation for F and plotting against the corresponding deflections from the deflection-time curve, force-deflection curves for impact were obtained.

5. From a series of force-deflection curves for six beams of Douglas fir broken under a single blow and five beams broken in static cross-bending, all beams being cut from the same piece of timber, the following conclusions were drawn:

(*a*) The impact fibre stresses are almost double the slow bending stresses, at rupture.

(*b*) The energy of rupture in impact up to the ultimate load is twice that of static bending.

(*c*) The deflection at the ultimate load and the modulus of elasticity are about one-fourth higher for impact than the corresponding properties under static loading.

6. The mechanical properties of long-leaf yellow pine and spruce are higher in impact than the average values for the same properties in static bending.

7. The energy available is practically entirely consumed by the beam, supporting the contention that very little energy is lost in vibrations of the machine frame.

TABLE I.

Log of Impact Tests on Timber Beams.

No.	Kind of timber	Span, inches	Dimensions in inches	Drop of tup in inches	S Modulus of rupture, lb./in.	E Modulus of elasticity, lb./in.	Energy consumed to ultimate in in-lb/in³.	Deflection to ultimate, inches
1	Yellow pine	50	2 x 2 x 52	36	10,200	2,150,000	4.76	1.44
2	Yellow pine	50	2 x 2 x 52	48	22,200	4,000,000	11.8	1.60
3	Yellow pine	44	2 x 2 x 46	65	16,900	2,700,000	14.0	1.70
4	Yellow pine	44	2 x 2 x 46	70	15,600	3,000,000	11.8	1.50
5	Yellow pine	50	2 x 2 x 52	60	16,000	2,600,000	15.0	2.48
6	Yellow pine	50	2 x 2 x 52	70	17,750	2,500,000	17.3	2.50
7	Spruce	44	2 x 2 x 46	48	13,500	2,000,000	8.2	1.50
2x	Douglas fir	50	2 x 2 x 52	44	14,000	1,850,000	6.8	1.72
3x	Douglas fir	50	2 x 2 x 52	50	13,000	2,000,000	5.5	1.46
4x	Douglas fir	50	2 x 2 x 52	40	15,900	2,000,000	7.7	1.74
6x	Douglas fir	50	2 x 2 x 52	48	14,400	1,800,000	8.7	2.04
8x	Douglas fir	50	2 x 2 x 52	48	14,100	2,000,000	9.8	2.04
10x	Douglas fir	50	2 x 2 x 52	44	15,800	1,760,000	9.2	2.04

Weight of tup = 50 lb. Average weight of beam = 4 lb.

TABLE II.

Comparison of the Mechanical Properties of Douglas Fir in Impact and in Static Bending.

DOUGLAS FIR.

A = Average values for impact test on six beams.
B = Average values for static bend test on five beams.

Average values	*A* Impact test	*B* Static test	Ratio *A/B*
Maximum load in pounds	15,500	870	1.78
Deflection at ultimate, inches	1.84	1.50	1.23
Modulus of elasticity, lb./in.²	1,920,000	1,600,000	1.20
Modulus of rupture, lb./in.²	14,500	8,150	1.78
Energy consumed to ultimate, in-lb./in.³	7.94	4.00	1.98

TABLE III.

Comparison of the Energy Available and the Energy Consumed by Beams Broken in Impact.

No.	Kind of timber	*A* Energy available, foot-pounds	*B* Area under Force-defl. curve, foot-pounds	Per cent. difference between *A* and *B*
1	Yellow pine	145.7	138	5.28
2	Yellow pine	207.2	208	−0.4
3	Yellow pine	250	252	−0.8
4	Yellow pine	270.7	262	3.2
5	Yellow pine	273.8	264.7	3.3
6	Yellow pine	291	304	−4.5
7	Spruce	201	201	0.0

The Use of Titanium in the Manufacture of Steel Castings. W. A. JENSSEN. (*Proceedings of the American Foundrymen's Association,* September 11–15, 1916.)—Notwithstanding all that has been said regarding the harmful effects of phosphorous and sulphur in steel castings, occluded gases and oxides are the real causes of many of the troubles of the steel foundryman. In the elimination of these difficulties, ordinary dioxidizers such as ferro-manganese and ferro-silicon have their place, but if the best results are to be achieved a more potent reagent is necessary, and for this purpose ferro-titanium has proved unusually satisfactory. Titanium undoubtedly is one of the most powerful dioxidizers and denitrogenizers known. The chief value and merit of titanium lies in its positive action in the removal of occluded oxides, nitrogen and entrapped slags. The present-day method of using ferro-titanium is to augment the incompleted cycle of reactions with ferro-titanium after the other deoxidizers have been added. Ferro-titanium additions are of value to the foundryman in making low or high-carbon or alloy steels. The results are not due to any direct or alloying effect of the titanium, but rather to its value as a deoxidizer and cleanser in removing harmful occluded gases and slags. Titanium, however, must not be looked upon as a cure-all to rectify the evils of poor stock selection and bad furnace practice. Its function is to make good steel better. In these days of high priced ferro-manganese, ferro-titanium can be used to advantage to decrease the consumption of the manganese alloy.

A NATIONAL DEPARTMENT OF PUBLIC WORKS OUR NATION'S NEED.*

BY

ISHAM RANDOLPH, D.Eng.

Member of the Institute.

SINCE the Franklin Institute *is*, as the philosopher and patriot, whose name it memorializes, *was*, concerned with all of the arts and sciences and with all movements, which are in their essence for the betterment of mankind in general and of the American people in particular, I make bold to offer for the consideration of its faculty and members a suggestion which is fraught with vast possibilities for good to the American nation. That suggestion I present in the form of a bill for the creation of a new department of government to be known as the National Department of Public Works. Observations resulting from personal contact with the various agencies which now conduct the Public Works of the United States, extending over a period of about thirty years, have served to convince me that these various agencies should give place to centralized authority, and centralized responsibility. My crystallized convictions find expression in the following bill:

A BILL TO CREATE AND MAKE EFFECTIVE A NATIONAL DEPARTMENT OF PUBLIC WORKS.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled:

That the creation of a Department to be designated and known as the Department of Public Works of the United States is hereby authorized. The head of this Department shall be designated as the Secretary of the Department of Public Works and he shall be appointed by the President of the United States with the consent of Senate thereof and he shall be a member of the President's Cabinet.

The first duty of the Secretary of the Department of Public Works shall be to perfect a working organization for the purpose

*Communicated by the author.

of carrying on all of the public works of the United States other than those which pertain to National Defense or work wholly relating to navigation and light house construction and service.

He shall appoint a Commissioner of Public Works who shall be a man of recognized ability and successful accomplishment along lines of engineering science and construction.

This election and appointment shall be made with the full knowledge and approval of the President of the United States and the man so appointed shall hold office until disqualified by physical or mental infirmity, old age, moral delinquency or demonstrated unfitness. In consultation with the Secretary, the Commissioner of Public Works shall organize office and field forces sufficient in number and suitably qualified to carry out the intents and purposes of this act, which are as follows:

To carry to completion all constructive works, such as public buildings, levees, dams, roads, bridges, structures and improvement works of every description and kind authorized and provided for by Congress and placed under the jurisdiction of the Department of Public Works.

To secure physical data pertaining to rivers, swamps, arid regions, to procure existing maps showing the natural and political divisions of the United States and its territorial and insular possessions.

To secure copies of all topographical maps of accepted reliability and to make topographical surveys of all areas under the control of the United States within which accurate knowledge of the earth's surface seems either necessary or desirable.

To study the meteorological data which has been accumulated by Governmental or other agencies with a view to determining flood expectancy.

To study the characteristics and capacities of the streams of the country for the purpose of determining what had best be done, and how, to avert flood disaster.

To select suitable reservoir sites for storing flood waters with the purpose of lowering the flood planes of streams and later, releasing the waters so stored for the purpose of aiding navigation during dry periods and emptying the reservoirs in advance of recurring excessive precipitation.

To study those drainage problems which by reason of civil divisions are interstate in their scope, and to devise plans for

draining swamps and overflowed lands in coöperation with States, Counties, Townships, or Municipalities upon an equitable basis of division of cost.

To select available sites for the development of water power.

To gather and preserve data relating to arid lands and the sources from which water may be secured with which to irrigate these lands.

To prepare plans for such structures as it may be necessary or desirable to build in carrying out the purposes of this bill as hereinbefore set forth, together with estimates of cost and recommendation relating thereto.

Those works to be first considered and reported upon, the importance or necessity of which has been demonstrated by disasters creating National sorrow and sympathy, for the purpose of reclaiming lands laid waste by such disasters and restoring them to the Nation's sources of wealth production and permanently thereafter preventing a recurrence of like disaster.

The Secretary of the Department, with the approval of the President, shall present to Congress at each session such projects as he deems meritorious and for which there seems to be an urgent need, together with estimates of cost and his recommendations thereon.

The Secretary shall present each year a report of the operations and expenditures made in accordance with the intent and purposes of this bill and he shall prepare and present a budget setting forth the financial needs of his department, both for administration and constructive work for the fiscal year next ensuing.

The salary of the Secretary of the Department of Public Works shall be the same as that of the Secretary of War, and the salaries of the employees of the Department shall be determined by the Secretary with the advice of the Commissioner of Public Works and the approval of the President.

All coastal harbors shall remain as now in charge of the War Department. All navigable rivers above their harbor entrances shall be under control of the Department of Public Works.

All projects for improving waterways and for protecting adjacent lands and properties from damage due to shifting river channels or to overflow in times of flood, originated by persons, corporations, communities or municipalities, must be submitted

to the Secretary of the Department of Public Works and receive his approval before any of the work contemplated in the project is entered upon.

Where projects dependent upon Federal coöperation and financial aid are presented, the extent of that coöperation and the measure of financial aid must be passed upon by the Secretary of the Department of Public Works and he must submit his conclusions and recommendations to Congress.

The execution of any and all projects in which the Government coöperates shall be under the direction and control of the Department of Public Works.

The transfer of the several bureaus or departments now engaged in carrying on the various classes of work which it is the purpose of this act to place under the control of the Department of Public Works, shall be made in such manner as not to hinder or retard any necessary work now in progress; but the transfer shall be made as speedily as is consistent with this requirement, and all such transfers shall be completed within one year from the date of the passage of this act.

To defray the expense of organizing the Department of Public Works of the United States and to maintain the same until the Secretary submits the first budget setting forth the needs of the Department, the sum of Five Hundred Thousand (500,000) Dollars is hereby appropriated which shall be paid out of the treasury of the United States upon warrants drawn by the Secretary of the Department of Public Works.

This is the bill as it comes from a mind unskilled in statecraft, unversed in legislative nomenclature, and it is presented only as a suggestion for the lawmakers whose experience and learning qualifies them to build upon this suggestion, a law free from the imperfections which one would naturally look for in the work of an amateur.

Let us consider some of the arguments in support of the claim that a National Department of Public Works is a National necessity.

Not only did I present this bill to the Third Annual Convention of the National Drainage Congress, but I sent a copy to President Wilson. Also I presented copies to our Secretary of State, to our Secretary of Interior and to certain of our national

legislators. I received an acknowledgment from the President through his secretary. I talked with Secretary Bryan about it and he expressed the view that it would come at some future time, but that I would not live to see it. The Secretary of Interior, Mr. Lane, was most sympathetic and friendly to the idea. Senator Ransdell expressed his approval of the bill, but told me that unless I could get the country back of it, Congress would never touch it.

How can a lone civil engineer ever get the great American people to back up a proposition like this? Never can he accomplish it unless he can enlist great organizations like The Franklin Institute in a crusade to bring it about.

Men, of this great society, let me tell you why I think a National Department of Public Works is needed.

This great nation of ours finds out gradually what it needs. In its very genesis, it knew it needed a Department of State, for young as it was, it had to deal with the nations of the earth. It knew it needed a War Department, for it had by war won its way to independence and a place among earth's governments. It knew it needed a Treasury Department, for it must collect and disburse revenues, issue a medium of exchange and protect the country's credit. It knew it had to have a Department of Law, presided over by an Attorney-General, for it had to know and keep within the bounds of international law and to deal with interstate law affecting the interests of its citizens and those of the stranger within its gates.

Those were the four original departments having Cabinet representation.

The need for a Navy Department was manifest, for a navy had to be built up and maintained to protect its maritime commerce and to uphold upon the high seas the honor of its flag, but the demand for this was not met until 1798.

A post-office organization was kept up for thirty-five years before it was made a national department whose executive head was given a place in the Cabinet. This came to pass in 1828.

Its vast territory and the care of its wards, the aborigines, called for the exercise of particular and responsible supervision, and this call was met by the creation, in 1849, of the Department of Interior.

As time went by other needs developed; since from the soil

comes man's sustenance and wealth, just recognition of its importance was made by the creation in 1889 of the Department of Agriculture.

The growth of one hundred and fourteen years demonstrated the need of a Department of Commerce and Labor, and it was created in 1903. March 4, 1913, Commerce and Labor were segregated and now we have the Department of Commerce and the Department of Labor.

The heads of all these departments are members of the President's official family; they are his Cabinet advisors.

And now "in the fulness of time" another national need is recognized and its supply should not long be delayed. The need is for a National Department of Public Works.

The public works of the United States are vast in their scope and of immense importance. Some of the things that ought to be done are in process of accomplishment, but they are few in comparison to the needs of a land whose material advancement is held back because needed work along many lines is not even attempted. The work that is being done is not concentrated in one department under one responsible head, but apportioned off to several departments whose responsibilities and whose efforts are not correlated. The Treasury Department has charge of public buildings. Is there any correlation between scientific finance and scientific building? Does the training which fits a man to be at the head of the National Finances also fit him to pass upon architectural design and structural sufficiency?

The work of reclaiming arid lands, involving as it does vast engineering structures, is confided to the Department of Interior, as is the research work conducted by the Geological Survey. The Department of Agriculture is charged with the engineering involved in drainage investigations and road building. The War Department has charge of the national defenses as is eminently proper; there is the appropriate field for the military engineer. But it also has charge of all the rivers and harbors of the United States and its acquired territory, together with the building of all canals, the cost of which is defrayed by the nation.

Now these activities are carried on by the several departments named, each independent of the other, without correlation or coöperation, and it ought not to be so. These activities should all be aggregated in one department under one responsible head who

should be a member of the President's Cabinet and the peer of his fellow-members.

Then, and not until then, will proper plans, upon broad and comprehensive lines, be worked out and carried persistently to a conclusion which will give results commensurate with the public need and worth the vast expenditure of the people's money.

What we need is a plan big enough to compass the land and so well considered that the work most needed can be first begun and, when it is finished, it will be so much accomplished in the development of the great comprehensive project; and so let each successive component section of the plan be taken up in the order of its need until the last section is reached and the mighty work stands complete; a monument to the brains that planned and the energy, skill and well-applied labor that accomplished all. Such a work as this is not for a decade or a lifetime, but to be carried forward long after its designers have been gathered to their fathers.

But it is not necessary to fold our national hands and wait until this vast plan is all worked out and presented to the Nation. There are things to be done now, so obvious and so necessary that they are at once recognized as integral parts of any great comprehensive plan.

The vastness of the land suggests the immensity of the plan which must be evolved to meet its needs. The continental holdings of the United States, including Alaska, are given as 3,742,583 square miles. Within the United States proper, there are 26,410 miles of navigable rivers, 75,000 square miles of swamp lands and 1,200,000 square miles of arid lands. The entire coast line of continental United States and its insular possessions is given as 48,881 miles. There is a field of operations which must arouse patriotism and stir ambition. These rivers must be improved and made more useful to the commerce of the land. They must be given a capacity adequate to carry the floods which vast water sheds pour into them, or where possible, the intensity of these floods must be abated by partial storage in reservoirs which will give up their stored waters when stream conditions render it safe to release them; that release being subject to judicious control. And, wherever possible, these streams must be made to yield all the power that head and volume of flow can generate.

These 75,000 square miles of swamps must be recovered; the

soil wealth which has been accumulating for "time out of mind" must be taken from the frogs and the reptiles and given to man for tillage with an assurance that no "garden of the Lord" ever yielded a richer bounty Those 1,200,000 square miles of arid lands must be made to fulfill the prophecy of Isaiah, "the desert shall blossom as the rose." For the sons of America will need all of these lands as the 100,000,000 of to-day will be 200,000,000 at no far distant to-morrow, and the increase will go on until there is no place in the whole land without an inhabitant. Is it too soon to begin doing all of these things with energy and zeal? We know that the delay has been too long already. And yet our lawmakers hang back.

In what I am about to say, I wish to make clear in advance that my remarks are not actuated by hostility to the United States Engineer Corps, for every citizen of the United States must be proud of the record these men have made and admire the integrity of an organization which has been a distinguishing characteristic of these splendid men. I speak more particularly of them because the horizon of their work is only bounded by the horizon of the country that they serve.

For more than thirty years I have been in contact with the men of the Corps of United States Engineers and I know their virtues, which are many, and their failings, which are few; failings theirs by reason of their humanity and not because of their training. I have throughout these years been on the opposite side of nearly every question which has brought me in contact with them and as a result I have learned to love these my constructive enemies. I have found them firm in their convictions, though, from my standpoint, often narrow in their views, loyal to their duty and their corps and honorable in their dealings. I fault not their efficiency, but their numerical inadequacy.

I find in "Form 87, War Department, Office of Chief of Engineers, Washington, January, 1916," a statement showing the rank, duties and address of the officers of the Corps of Engineers, U. S. Army, that there are but 232 engineers of that corps in active service. Of these, eleven are in the Philippines, four in Hawaii, ten on the Panama Canal and twelve are detailed as instructors and two are on Legation duty. This leaves 193 men, and of that number 64 are First Lieutenants and 28 Second Lieutenants; now lieutenants are about as capable of taking charge of public

works as are the young graduates from our engineering universities, and he would be truly confiding who would trust one of these fledglings with an important piece of construction; so that the available U. S. Engineer Corps is whittled down to one hundred and one experienced men and from that number must be subtracted the men whose duties are connected with the office of the Chief Engineers and the War College in Washington. The distinguished remainder cannot cope with the requirements of 26,410 miles of interior waterways, 48,881 miles of seacoast, national fortifications, government canals and miscellaneous work. These works must go on and the numerical deficiency must be made up from the ranks of the civilian engineers. The natural, the inevitable, result is that the engineering of the United States is mainly done by civilian engineers. The military engineer too often becomes an executive officer, affixing his signature, *pro forma*, to plans in the preparation of which he has had very little hand.

In the thirty-six years that I have lived in Chicago, there have been ten United States Engineers in charge of the work of that district, one of these, W. L. Marshall, later justly honored as Chief of Engineers, was in charge of the Chicago District for eleven years, and during all of that time there has been but one civilian assistant engineer in subordinate charge. About the time that an engineer officer has been inducted by his civil assistant into his duties and really becomes master of conditions and cognizant of the needs of a district, he is—like the Methodist minister—moved to a new field of duty.

Nor is this the worst of it. Genius in the United States Engineer Corps is cramped and initiative is repressed, these men must not originate; they may and do recognize needs in the Districts to which they are assigned, but suggestions are not welcomed in Washington. Until Congress orders investigations and reports, the army engineer may not ascertain facts (or if he does, he must keep them to himself) nor report conclusions. All of this reacts upon the civilian assistants; they become routine men, doing what they are told faithfully and well, but they soon part with all idea of initiative.

The natural result of this shortage of United States Engineers is delay in carrying on work which they are called upon to perform—in addition to regular duties—as members of Engineering Commissions. I will make a citation or two in support of this

statement and I wish it distinctly understood that I have no thought of censure for the men who compose the commission of which I speak.

In 1902, Congress ordered surveys, estimates and a report on a fourteen-foot waterway from Chicago to St. Louis, and provided $200,000 to defray the cost of it. The commission to whom this work was intrusted was composed of distinguished engineer officers. They employed parties of civilian engineers, in direct charge of a civilian engineer, and put them into the field to ascertain the facts. The surveys were made; the data thus secured was compiled and maps and profiles based thereon were prepared. The commission made its report in 1905, showing that the project was practicable; but, that in the judgment of the commission, there was no commercial justification for the building of the waterway. Later, for some reason, Congress called for another report on this same waterway extended to Cairo, and a board was formed composed of four military engineers and one civilian. This board had for its use all of the information secured by the previous board at a cost of $200,000 and all of the information collected by the Mississippi River Commission. It began its work in November, 1910. The report made by the board in February, 1911, as is shown by the last paragraph thereof, was not final, and certain features upon which it was required to report were not then covered. The final report of this commission was transmitted to Congress by the Secretary of War February 18, 1914, and became H. R. Doc. 762, 63rd Congress, 2nd Session. Why this delay of three years? Presumably because the members of that commission were so burdened with their regular duties that they had not time to bestow upon this superadded requirement. They were busy men and the things which had to be done they did, and left the matters which could wait until they could get around to them.

There are two features of the suggested bill that seem to me to be of especial importance; first, the appointment of a Commissioner of Public Works, " who shall be a man of recognized ability and successful accomplishment along lines of engineering science and construction . . . The man so appointed shall hold office until disqualified by physical or mental infirmity, old age, moral delinquency or demonstrated unfitness." Next, that requirement that the " Secretary of the Department, with the

approval of the President, shall present to Congress at each session such projects as he deems meritorious and for which there seems to be an urgent need, together with estimates of cost and his recommendations thereon."

The carrying out of this requirement would serve to correct an abuse which has led to scandal and waste. No project for a public improvement can now be reported on unless Congress orders it and getting Congress to order such a report becomes the task of the interests locally concerned in the improvement. These interests must secure influence sufficient to get their project a hearing and this makes business for lobbyists and gives the local Congressman a chance to make political capital by boosting the game. With such a department as is here advocated and such a requirement in the law creating it, a broad view of the whole national estate would be taken and the needs of every section of the country would be impartially presented upon the basis of merit and not of political expediency.

Just now the demand for National preparedness overshadows any appeal for a National Department of Public Works. Only a small percentage of our people realize the desirability of such a department, but the reverberation of the guns that make Europe tremble have thrilled all of our people and made us think of our defenselessness. To the south of us there has been a threat of war, which, had it come, would have contrasted with the death grips of the nations of Europe, as picket firing does with the thunders of battle joined. That threat, however, has served to demonstrate our need of trained soldiers and a system which will develop them. Let us hope that the sorry spectacle of a small fraction of one per cent. of our population responding to the call to the colors does not measure the patriotism of the men of the nation. War has become an engineering science. Soldiers are no longer commanded to hold their fire until they "can see the whites of the eyes of the enemy," but they must by engineering methods locate the positions held by the enemy, and gunners, who will never see those enemies, must by mathematical determinations so train their guns as to destroy those enemies, not only before "the whites of their eyes" are seen, but before their bodies even are discernible upon the distant horizon. In war, to-day, cold steel cannot be used until metal hot from the cannon's mouth and reheated by predetermined explosion has cleared the way for it.

It takes men of science to accomplish these modern miracles of destruction and the Army engineers are trained to work these miracles, as well as to build defenses which will set the miracle of defense against the miracle of destruction. We have too few men trained in the science of war; the few so trained should not be taken from the vocation for which they have been trained to fill positions for which they have no special fitness.

A National Department of Public Works would be a far step toward national preparedness.

Electrolytic Zinc Dust. H. J. MORGAN and O. C. RALSTON. (*Proceedings of the American Electrochemical Society,* September 28–30, 1916.)—The sudden increase in the price of zinc dust after the beginning of the European War, owing to the cutting off of the German and Belgian supply, led to the conducting of some experiments on the possibility of its production on a commercial scale from solutions of zinc, and the substitution of zinc made in this manner for the zinc dust ordinarily used in the precipitation of gold and silver in the cyanide process. The production of electrolytic zinc sponge seemed the most feasible method of accomplishing this object, the sponge to be of such a nature that it would crumble to dust when dried.

Sponge metal can be obtained from zinc sulphate solutions by the continual addition of a small amount of either copper or arsenic salts to the electrolyte. The objection to the use of zinc dust prepared by this method is the needless dilution of the bullion caused by the copper and the danger met in the handling of gold and silver precipitates when arsenic is used to produce the sponge. The preparation of zinc sponge is also possible from sulphate solutions by keeping acidity low and temperature high. Zinc oxide, rendering the solution slightly basic, is the most desirable chemical for maintaining this condition. It is subject to the objection that it is only slowly and slightly soluble in zinc sulphate solutions. The same objections apply to zinc sponge prepared from chloride solutions, except that the zinc sponge seems to be more inclined to be oxidized during drying. Sodium zincate solutions allow of the deposition of zinc sponge under a widely varying range of electrical and thermal conditions. Stirring of the electrolyte must be avoided. Current efficiencies of about 60 per cent. and zinc dust precipitating efficiencies of 70 to 75 per cent. are possible. There seems to be no difficulty in getting one pound of zinc dust from a solution of zinc with 3 kilowat-hours of energy. Sodium zincate solution recommends itself because of its ease of preparation from caustic soda and zinc oxide, both of which are articles of commerce. The zinc tenor of the solution can be maintained either by the addition of more zinc oxide or by the use of zinc anodes, by which latter process spelter can be converted into zinc dust.

NOTES FROM THE U. S. BUREAU OF STANDARDS*

THE FAILURE OF BRASS.—1. MICROSTRUCTURE AND INITIAL STRESS IN WROUGHT BRASSES OF THE TYPE 60 PER CENT. COPPER, AND 40 PER CENT. ZINC.[1]

By P. D. Merica and R. W. Woodward.

[ABSTRACT.]

An investigation has been made of the causes of failure of a number of articles, particularly bolts, of wrought brass of the type 60 : 40, *i.e.*, such as naval brass, manganese bronze, etc., with particular reference to the microstructure of the material and the presence in it of initial stress. In the course of this investigation. the physical properties, microstructure, and initial stress distribution have been studied in some 250 materials, some of which had been in service in the Catskill Aqueduct construction, in the Filtration Plant of the City of Minneapolis, in the U. S. Navy Department, and in the Panama Canal construction, and some of which was new material, rods, having been kindly furnished by several manufacturers.

Measurement of initial stress was made largely by the Heyn method, other methods for approximate and rapid determination of such stresses are discussed and tested. A convenient and readily measurable initial stress " characteristic " value is that of the average stress without regard to sign. The initial stresses in brass rods and bolts tested varied greatly both in distribution and magnitude, average stresses from 1000 to 30,000 lbs./sq. in., fiber stresses of from 0 to 80,000 lbs./sq. in. were found; in extruded and forged rods compressional stress is found in the outside layers, in drawn rods on the other hand, the outside layers are in tension.

Some physical properties, the chemical analysis, and initial stress values of some typical materials tested are given in the following table:

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* Communicated by the Director.

[1] Technologic Paper No. 82.

Physical Properties.

B. S. No.	Material.	Chemical Analysis. Copper.	Zinc.	Tin.	Iron.	Tensile Strength. Ultimate strength lbs., sq. in.	Proportional limit, lbs., sq. in.	Elongation in 2 in., per cent.	Initial Stress. Average stress, lbs., sq. in.	Maximum fiber stress, lbs., sq. in.	Stress in outer layer.[2]
3	Manganese bronze....	60.0	38.6	0.78	0.5	70 000	17 000	33	25 000	44 000.	T
85	Naval brass..........	59.8	39.3	0.61	....	61 000	16 000	46	2 000	7 000	T
136	Manganese bronze....	59.1	39.3	0.78	0.70	72 000	27 500	44	22 000	34 000	T
160	Manganese bronze....	57.3	40.7	0.94	1.08	61 000	14 000	28[1]	30 000	84 000	T
172	Muntz Metal.........	59.4	40.2	....	0.02	64 000	36 000	40	4 000	8 000	C
174	Manganese bronze....	56.9	40.1	1.63	1.18	84 000	36 000	22	4 000	9 000	C
187	Naval brass..........	60.0	39.6	0.40	....	64 600	28 700	33	6 000	14 000	C
189	Manganese bronze....	56.6	40.8	1.00	1.50	61 600	24 000	..	8 000	12 000	C
205	Manganese bronze....	58.8	39.6	0.39	1.06	84 600	52 000	22	5 000	9 000	T

[1] Elongation over 3 in.
[2] C = compression; T = tension.

Materials 85, 136, 172, 174, and 205 were new, Nos. 3 and 160 had season-cracked in service, and Nos. 187 and 189 had been in service under moderate stress for months without showing signs of failure.

Failures by fracture or fissure have occurred in these materials,

(1) as a result of the presence of initial stresses of large values,

(2) as a result of service over-stress due for example to the drawing up of bolts too tightly, and

(3) as a result of improper and faulty practice in forging bolt heads, flanging plates, etc.

An average initial stress value of 500 lbs./sq. in. is to be regarded as a safe stress limit for rods and bolts of usual size; under normal service conditions, in which the service stresses are themselves not greater than from 5000 to 10,000 lbs./sq. in. Where the initial stress value or the sum of initial stress in tension and the tensional service stress approach the elastic limit of the material the material is likely to fail.

It was shown that the initial stresses in rods could be relieved by annealing for one or two hours at low temperatures, 300°C to 400°C, at which the physical properties were not appreciably affected.

DURABILITY OF STUCCO AND PLASTER CONSTRUCTION.*

By R. J. Wig, J. C. Pearson, and W. E. Emley.

[ABSTRACT.]

OWING largely to its general attractiveness the so-called "stucco house" has become very popular in recent years, especially in the suburban districts of large cities. In fact, the increase in the use of stucco for residence construction has been so rapid that there has been little opportunity to observe whether the methods and materials commonly employed in this class of construction will stand the test of time and insure satisfactory service and durability. In consequence many inquiries are received by the Bureau on this subject, a considerable number of them being prompted by the knowledge of failures or of cases in which stucco has not proven satisfactory.

* Technologic Paper No. 70.

Five years ago (in 1911) the Bureau in co-operation with the Associated Metal Lath Manufacturers undertook to carry out some exposure tests of metal lath plastered with various plastering materials for the purpose of determining the durability of different types of lath and the best methods of construction to insure the protection of the metal from corrosion. These tests (which are still in progress) have demonstrated that painted or preferably galvanized lath well embedded in a dense, water resistant stucco should preserve the metal indefinitely under normal conditions of exposure.

Not all of the plastering materials used in these tests were satisfactory, and it was the desire of certain manufacturers to have the tests repeated or extended with certain modifications in the mixtures and methods of application. In the meanwhile information was accumulating which indicated that corrosion of the metal lath was not by any means the only fault to be overcome in stucco construction, and suggested that an investigation of the entire subject would be of value to architects and contractors as well as to prospective home owners.

The natural interest of the manufacturers of cement, lime, gypsum, metal lath, hollow tile and many proprietary materials in this subject suggested the desirability of calling a conference and planning further work in co-operation with an advisory committee composed of members of the industrial organizations concerned, together with representatives of the Bureau. This committee was organized in 1914 and its membership now includes representatives from the Supervising Architect's Office of the Treasury Department, the American Concrete Institute, and three contracting plasterers of wide experience from as many large cities as well as representatives from the industries.

This committee by frequent conference and correspondence drew up a program for a comprehensive investigation of stucco construction to be followed later by an investigation of interior plaster construction. In 1915 the plans of the committee materialized in the erection of a test structure on the Bureau grounds containing 56 experimental stucco panels, each approximately 15 feet long and 10 feet high. The building itself is 200 feet long, 26 feet wide, and 24 feet high, the interior being available for the erection of plaster walls and partitions of various types. The stucco panels, which were completed in November, 1915, rep-

resent practically all the common types of stucco construction, a variety of mixtures being used on metal lath, wood lath, hollow tile, brick, concrete block, plaster board, gypsum block and concrete bases.

In April, 1916, a careful inspection of the condition of the panels was made and a progress report drawn up for publication together with a full description of the test structure. This report shows that only two of the 56 panels were entirely free from cracks six months after the panels were erected, and a number of them were in very poor condition. On the other hand about 40 per cent. of the panels were rated as satisfactory, the remainder being in various stages of deterioration. While the condition of the test panels as a whole is rather discouraging, it should be mentioned that the smooth type of finish employed, commercially known as sand float finish, is well adapted to bringing out the small defects, such as cracks, blotches, uneven texture, etc., and since it must be assumed that commercial stuccos are subject to these defects in even larger measure than the carefully constructed test panels, the advisability of using the rougher finishes is apparent.

Up to the present time the investigation has shown the necessity for further experimental work and no attempt will be made to draw up even tentative specifications until the results of this work can be compared and combined with the results of an extensive field investigation. In the latter an endeavor will be made to inspect the condition of stucco houses or buildings which have been standing preferably five years or longer, in order that reliable data may be obtained on the durability of different types of stucco on different bases in different parts of the country.

The present progress report does not, therefore, include definite recommendations for stucco construction, in accordance with the decision of the advisory committee that the tests have not gone far enough to warrant general conclusions. Nevertheless a study of the forms of construction and the present condition of the panels, which are fully described in the report, will yield much suggestive information to those who are especially interested in the subject.

SPECIFICATIONS AND TOLERANCES FOR WEIGHTS AND MEASURES AND WEIGHING AND MEASURING DEVICES.*

[ABSTRACT.]

Specifications and tolerances for weights and measures and weighing and measuring devices were first adopted at the National Conference on the Weights and Measures of the United States, held at the Bureau of Standards in May, 1913. These specifications and tolerances are designed for the use of inspectors of weights and measures in the tests made in the course of their official inspections. The purpose of the application of them is to eliminate from use weights and measures and weighing and measuring devices that are false, without prejudice to such apparatus as conforms as closely as is mechanically possible, to the official standards; or those which are of such construction that they are faulty, are not reasonably permanent in their indication or adjustment, or are designed to or may be used to facilitate the perpetration of fraud.

Since the original action of the Conference these specifications and tolerances have been adopted as official and put into force and effect in a number of States and cities by the officials of the States and cities concerned, and it has been demonstrated that they can be enforced without hardship and that their enforcement will do much toward eliminating false and fraudulent devices from commercial use. In this way the work of the State and city departments is facilitated and the consumer receives a greater protection from the weights and measures laws.

In order to obtain the greatest measure of efficiency from weights and measures laws and rules and regulations, it is very necessary that uniformity between the various jurisdictions be obtained. By the issuance of these specifications and tolerances there has already been secured a very desirable gain toward this end, and the outlook for a still greater measure of uniformity, through the action of additional States and cities, is very promising.

Since the first adoption of these specifications and tolerances additions and amendments have been made by the Conference from time to time, as opportunity was afforded to study and draft requirements for new types of apparatus coming within

* Circular No. 61.

the purview of the work of the weights and measures official, or as experience gained in the field had demonstrated that some changes were advisable. The experience of several years has now demonstrated that there has been secured a set of requirements which meet the needs of trade throughout the country.

The Bureau of Standards has been represented on the committee appointed by the Conference and the specifications and tolerances have the thorough and complete endorsement of the Bureau, which joins with the Conference in recommending the adoption of these specifications and tolerances by the States.

SPECIFICATIONS FOR AND METHODS OF TESTING SOAPS.*

[ABSTRACT.]

A GENERAL discussion of soap, including its definition, a brief description of the materials entering into its manufacture and the theory of saponification is followed by the enumeration of the chief varieties of soap and the requirements in each case. Recommended specifications are given for milled toilet, white floating, liquid, salt-water, two grades of laundry, and chip soaps which have been prepared after careful consideration of the opinions of both users and manufacturers. To this is added a section on the methods of sampling cake, liquid and chip soaps, the preparation of the samples in the laboratory and methods of analysis. The methods of analysis include the determination of volatile matter, free alkali or acid, alkali as carbonate, borate and silicate, sulphate of the alkali, matter insoluble in water, unsaponified matter, total fatty acids, titer test and neutralization values of the fatty acids, rosin, total alkali, chloride, anhydrous soap and qualitative tests for rosin and sugar.

* Circular No. 62.

How Oil Burners Help Boilers Over Peak Loads. ANON. (*Electrical World*, vol. lxviii, No. 16, October 14, 1916.)—By rearranging one of its boiler batteries into a front-and-rear-fired boiler, and by installing different systems of oil burners under other boilers, with provision for quickly changing back to coal firing in an emergency, the St. Joseph (Mo.) Railway, Heat, Light and Power Company has insured itself against possible operating difficulties due to shortage of either oil or coal. In addition, the efficiency of the boilers and of the station as a whole has been increased by the use of oil by making it possible to keep a minimum number of boilers in operation.

The overload rating of one of the boiler batteries was increased from 120 per cent of full load rating to 250 per cent by making simple alterations in the boiler interior and installing oil burners at the rear. Under normal load, this battery is operated at about 120 per cent full load rating, using only the chain grate stokers. During peak load, the additional capacity is secured by turning on the oil burners at the rear instead of firing additional boilers. With one battery firing coal only and another firing coal in the front and oil in the rear, and still another in which the oil fixtures can be quickly removed and the stokers already in place put in service, a scarcity of oil can cause no serious operating trouble. With one battery firing oil only and another firing oil above the grates, and still another firing oil from the rear, a scarcity of coal may be readily coped with. In normal operation the coal-fired boilers are worked under practically constant fire, and the fluctation in load is taken care of almost entirely with the oil-fired boilers which lend themselves readily to control.

Galalith in Germany. H. H. MORGAN. (*U. S. Commerce Reports*, No. 238, October 10, 1916.) Under the name "galalith," a bone-like substance similar in many respects to celluloid, has been on the German market for some time. Galalith is manufactured from casein by means of formaldehyde. A solution of casein is obtained by treating skimmed milk with caustic alkali. The solution is clarified and the casein precipitated by means of acids and then filtered. The water is then partly extracted by pressure and the product dried very slowly. The drying process extends over a period of several weeks. The casein plates thus obtained are thoroughly saturated with formaldehyde and dried again. The product is somewhat transparent, of a yellowish-white color, and very similar to horn.

Galalith is an excellent insulating material, and may be utilized either in the cold state or after it has been softened by using hot water. It is free from odor and is not so inflammable as celluloid, but is never entirely transparent, and it is not possible to manufacture it in very thin sheets. Its specific weight is 1.317 to 1.35; the hardness is 2.5 according to the Mohs scale. The largest manufacturer of galalith in Germany is the Internationale Galalith Gesellschaft at Hamburg.

NOTES FROM THE PHYSICAL LABORATORY OF THE UNITED GAS IMPROVEMENT COMPANY.*

VARIATION OF THE WAVE-LENGTH SENSIBILITY OF PHOTOELECTRIC CELLS WITH TIME.

By Herbert E. Ives.

IN order to use the photoelectric cell in photometry it is essential that the cell have two qualities. First, the relationship between illumination and current should be rectilinear; second, the wave-length sensibility curve must be of permanent character, and for reasons of practicability it should be the same from one cell to another, in order that any means for screening to copy the wave-length sensibility curve of the eye would not have to be worked out separately for each cell.

An investigation of the first point by the writer established the fact that photoelectric cells as previously made for photometric purposes could not be relied on to give the rectilinear relationship. Further study developed the explanation for this, and led to the design of a type of cell in which the current is strictly proportional to illumination. A simultaneous study of the wave-length sensibility characteristics of a number of cells showed these to be widely variant. The present work is part of an investigation being carried on to develop if possible cells of uniform and permanent characteristics, the question of *permanency* being first under study.

The particular cell studied has potassium for the active metal, which is deposited on the inner walls of a three-inch diameter bulb, leaving only a small spot clear for the entrance of the light. The potassium was colored by a hydrogen glow discharge, and the bulb afterward filled with helium gas at a pressure to give the maximum photoelectric current under working conditions.

Measurements of the wave-length sensibility curve have been made at intervals over a period of eight months, during part of which time the cell has stood unused, part of the time it has been used for routine spectrophotometric measurements, and twice it has been exposed for an extended period to a considerable illumination with voltage applied so that a photoelectric current passed continuously.

The result of this test is to show a gradual change in the shape of the wave-length sensibility curve, corresponding to either an increase of red or a decrease of blue sensitiveness, probably the

* Communicated by the Chief Physicist.

latter. The relative blue and red sensitiveness has changed in the period mentioned by roughly forty per cent. Time, rather than the amount of exposure of the cell, appears to be the determining factor. A slow diffusion of the sensitizing hydride layer into the pure alkali metal layer beneath is a possible explanation. The experiments will be continued.

HUE DIFFERENCE AND FLICKER PHOTOMETER SPEED.

By Herbert E. Ives.

THE critical speed of the flicker photometer at its equality setting has always been considered and treated by the writer as a function of the hue difference. Critical speeds for the spectrum, compared with a carbon lamp standard, published some years ago, showed a minimum in the yellow, which was ascribed to the hue distance between the yellow carbon lamp and spectrum at that point being smaller than at any other point. Recently Troland has obtained similar curves which he interprets as being reciprocals of the luminosity curve, on the ground that the low critical speed means greater *whiteness,* which he identifies with brightness.

In the paper of which this is an abstract the exact relationship between speed and hue difference is worked out on the basis of the theory recently developed and confirmed by experiment. It follows from this theory that the minimum critical speed in comparing the spectrum against any colored light occurs at the wavelength which is distant from the spectrum the least number of hue steps. If the comparison lamp is red, the minimum speed is in the red, if blue, in the blue, if yellow-white, in the yellow, but with a much higher speed at the blue than at the red end, while for a true white (5000° black body) the curve is symmetrical about a minimum in the green. The hue distances were worked out from the color sensation and hue difference data of Koenig and Steindler.

The experimental work was carried through with the new polarization flicker photometer, fitted to a constant deviation spectrometer. Curves of the predicted type were found in each case. Since the luminosity curve remains fixed, no matter what the color of the comparison lamp, these speed curves, with their minima occurring at any point one desires in the spectrum, show the "reciprocal of the visibility curve" idea erroneous.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, November* 15, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 15, 1916.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 0.

The paper of the evening was presented by Jacques Loeb, M.D., D.Sc., Ph.D., Head of Department of Experimental Biology, Rockefeller Institute, New York, on "The Production of Normal Animals from Unfertilized Eggs by Physico-Chemical Means."

The speaker described the means by which normal larvæ can be produced from unfertilized eggs of marine animals and called attention to the conclusions which can be drawn from these experiments concerning the mechanism of natural fertilization. The production of normal frogs from unfertilized eggs was next considered as well as the question of their sex. A full explanation of the various stages of fertilization and development was also given.

The subject was illustrated by diagrams, lantern slides and specimens of frogs produced from unfertilized eggs.

After a vote of thanks to the speaker the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, November* 1, 1916.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 1, 1916.

MR. C. E. BONINE *in the Chair.*

The following reports were presented for first reading:

No. 2668.—Linear Hot-Wire Anemometer.

No. 2677.—"Midget" Marvel Flour Mill.

The following reports were presented for final action:

No. 2675.—Sharples Super-Centrifuge.
Edward Longstreth Medal of Merit to The Sharples Specialty Company, of West Chester, Pa., adopted.

No. 2638.—Herr's Continuous Automatic Centrifugal.
Final action deferred.

No. 2658.—Copes Boiler Feed Regulator. Advisory.

R. B. OWEN,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A stated Meeting of the Section was held in the Hall of the Institute on Thursday, October 26, at 8 o'clock P.M. with Dr. Harry F. Keller in the chair. The minutes of the previous meeting were approved as read. John Johnston, Sc.D., of the Geophysical Laboratory of the Carnegie Institution of Washington, Washington, D. C., read a paper on "Some Effects of High Pressure." The apparatus used for the production, application and measurement of high pressures—pressures as high as 30,000 atmospheres—was described, and certain parts of the apparatus were exhibited. The influence of high pressures on such properties as volume, melting point, and electrical resistance was discussed; and stress was placed upon the fact that temperature and pressure are analogous variables. The communication was discussed, and, on motion of Dr. Walton Clark, a vote of thanks was extended to Dr. Johnston. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A stated meeting of the Section was held in the Hall of the Institute on Thursday, November 2, 1916, at 8 o'clock P.M. Dr. Gellert Alleman occupied the chair. The minutes of the previous meeting were approved as read.

A. V. Bleininger, B. S. C., Ceramic Chemist, Bureau of Standards, Pittsburgh, Pa., delivered a lecture entitled "The Development of the Ceramic Industries in the United States." The various classes of ceramic raw materials were discussed, and special reference was made to the resources of the United States, and to recent applications of the principles of colloidal chemistry in the purification of kaolin. A description was given of the changes produced by the action of heat on kaolin (dehydration, polymerization, sintering, and fusion), and of the influence exerted by these changes on the porosity, density, and viscosity. The minute structure of pottery was discussed. The manufacture of structural clay products, refractories, stoneware, whiteware, and porcelain received attention; and various forms of machinery used in the industry were described, especial stress being placed on the adaptation of the principle of the tunnel kiln to American conditions.

An interesting discussion followed the lecture; a vote of thanks was extended to the speaker of the evening, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A stated meeting of the Section was held on Thursday, November 9, 1916, in the Hall of the Institute at 8 o'clock P.M. Dr. George A. Hoadley occupied the chair.

P. G. Nutting, Ph.D., Director of Research Laboratory, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., delivered a lecture entitled "The Fundamental Principles of Good Lighting." Dr. Nutting

stated that criteria for proper lighting rest ultimately with the performance of the eye itself; that is, upon the ease, comfort and precision with which the eye functions. The eye adapts itself to certain lighting conditions with extreme facility, to others with great difficulty or not at all. Data on visual sensibility, efficiency and tolerance were reviewed. From these are deduced the principles governing visually efficient lighting at each of the four lighting levels with which we are concerned. Ideal lighting was described and finally applications to practical lighting were outlined.

After an interesting discussion by Dr. Herbert E. Ives, Mr. Norman Macbeth, and others, a vote of thanks was extended to the speaker of the evening and the meeting adjourned.

T. R. PARRISH,
Acting-Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, November 8, 1916.)

RESIDENT.

MR. JOHN C. BULLITT, 3D, 222 South Nineteenth St., Philadelphia, Pa.
DR. FARRY R. M. HITCHCOCK, 4038 Walnut St., Philadelphia, Pa.
MR. I. N. KNAPP, Engineer, The United Gas Improvement Company, Broad and Arch Sts., Philadelphia, Pa.
MR. JOHN M. MCCHESNEY, General Manager, Keystone Leather Chemicals Company, and for mail, 150 West Central Ave., Moorestown, N. J.
MR. IRVING B. SMITH, Chief of Research Department, Leeds & Northrup Company, Philadelphia, Pa., and for mail, Ambler, Pa.
MR. HOLLINSHEAD N. TAYLOR, Manufacturer of Tin Plate, 300 Chestnut St., Philadelphia, Pa.

NON-RESIDENT

MR. ARTHUR E. CHILDS, President, Massachusetts Lighting Companies, 77 Franklin St., Boston, Mass.

ASSOCIATE.

MR. CHARLES N. WEYL, Student, 6506 Lincoln Drive, Germantown, Philadelphia, Pa.

CHANGES OF ADDRESS

MR. WILLIAM N. ALLEN, 557 Church Lane, Germantown, Philadelphia, Pa.
MR. IRWIN A. BECKER, 2839 Ellis Ave., care of Michael Reese Hospital, Chicago, Ill.
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NECROLOGY.

Mr. Theodore N. Ely was born at Watertown, N. Y., on June 23, 1846, and died at his home in Bryn Mawr, Pa., on October 28, 1916.

He was educated at the Rensselaer Polytechnic Institute and was graduated in 1866 as a Civil Engineer.

In 1868 Mr. Ely entered the Civil Engineering Department of the Pennsylvania Railroad and during the forty-three years that he was engaged in railroad work he was Assistant Engineer of the Philadelphia and Erie Division, Superintendent of the Middle Division, and Superintendent of the Philadelphia and Erie Division and Assistant General Superintendent of Motive Power of the same Division, and prior to his retirement in 1911 he was Chief of Motive of the Pennsylvania Railroad lines East and West of Pittsburgh.

Mr. Ely was a member of the leading engineering societies of the United States and Great Britain, and was also connected with the important clubs of New York, Philadelphia, and Washington.

He became a member of the Franklin Institute in 1877.

Mr. George W. Spiese, 1642 Green St., Philadelphia, Pa.

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BOOK NOTICES.

DISEASES OF OCCUPATION AND VOCATIONAL HYGIENE. Edited by George M. Kober, M.D., LL.D., Professor of Hygiene, Georgetown University, Washington, D. C., President of the Section on Hygiene of Occupations, XV International Congress on Hygiene and Demography, Chairman of the Section on Industrial Hygiene of the American Public Health Association (1915), Secretary of the Association of American Physicians, and William C. Hanson, M.D., formerly with the Massachusetts State Board of Health, Pp. 918, 42 figures. Philadelphia: P. Blakiston's Son and Co., 1916.

Great Britain, France, Germany, Switzerland, and Bulgaria have incorporated into their laws the principle of compensation for occupational accidents and diseases. The United States Government and 33 of the states have during the last few years applied the idea to accidents, but as yet only Massachusetts and California recognize occupational diseases as compensable. An active campaign is now, however, being waged for these measures widely in this country. This is forcing employers, employes, legislators, and the American public generally, as well as physicians, to seek accurate data regarding occupational hazards, their mode of operation and final effects, and efficient means of preventing them. Much has been contributed to the literature of the subject by continental Europe and England, but until recent years comparatively little has been published in the United States. What has appeared in this country has been largely in the form of monographs from individual investigators and government reports.

Kober and Hanson's book is an attempt to summarize and co-ordinate the results of these recent investigations in such a way as to make them available

for reference and at the same time to supply the medical profession with an authoritative text book upon the recognized occupational diseases.

The first part is written primarily for the physician and is a systematic presentation by twenty-two specialists of the specific and systemic diseases of occupation. The second part is contributed largely by Dr. Kober himself and treats of the causes of occupational diseases and of the means of preventing them. The hazards of the various occupational processes are detailed and measures suggested by which they may be minimized or eliminated. In the final portion of the book the contributions are from men whose interests lie in the relation of hospital and medical school work, statistics, government study, and legislation to occupational diseases.

The book is a valuable asset to industrial medical literature. The eminence of its collaborators, such as Emery R. Hayhurst, Frederick L. Hoffman, Alice Hamilton, Luigi Devoto (professor and director of the Milan Clinic for Occupational Diseases), Frederick S. Lee, Thomas M. Legge, Sir Thomas Oliver, Ludwig Teleky, as well as the senior editor, is an indication of its authoritativeness and its classic character. Its range of subjects and the exhaustive references to the original sources at the end of each chapter make it invaluable as a reference work. While not the first American treatise upon the subject, it is the most comprehensive.

T. GRIER MILLER, M.D.

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Catalyzer Poisons in the Hydrogenation of Fatty Oils. C. ELLIS and A. A. WELLS. (*Journal of Industrial and Engineering Chemistry*, vol. viii, No. 10, October, 1916.)—One of the main difficulties in the hydrogenation, by the aid of nickel catalyzer, of many low-grade oils, such as some of the fish and whale oils, is that the life of the catalyzer is very short. The fact that in some cases a catalyzer does not last indefinitely and that its life is prolonged in proportion to the purity of the oil indicates that there are present in some fatty oils certain substances which unfavorably affect the catalyzer acting as poison thereto, and sooner or later causing the catalytic agent to become inactive. It has been observed that some kinds or grades of oil may be hydrogenated to an incomplete degree but that they cannot be carried beyond this point, no matter how long the treatment is continued, without change of catalyzer. If to these semi-hardened oils a fresh quantity of catalyzer is added, the hardening will usually proceed to complete saturation. In some cases, a fresh quantity of oil may be treated with seemingly spent catalyzer, when partial hardening will occur. An additional quantity of catalyzer will sometimes carry the oil so treated to completion, showing that the substance which affects the catalyzer is apparently taken up by it under these circumstances, thus leaving the oil in a condition to be readily hardened. Some oils which cannot be readily hardened without a preliminary purifying treatment, may first be agitated with a spent catalyzer, the catalyzer removed, and the oil then incorporated with a fresh quantity of catalyzer when hardening readily occurs.

Experiments with several detoxicating agents added to the oil indicate the effectiveness of copper hydrate. The oil, first having been filtered to remove the resulting copper compound, readily hardened. The copper hydrate used to detoxicate cod and other oils was examined to determine what bodies were taken up from the oils by the treatment. Sulphates were found but no evidence of the presence of phosphates or chlorides was obtained. A blank test on the original copper hydrate showed no sulfates or sulfur present, indicating that sulfur compounds are removed from fatty oils containing them by treatment with copper hydrate.

CURRENT TOPICS.

Origin of "Petrified Forest." ANON. (United States Geological Survey Press Bulletin, No. 286, September, 1916.)—The "Petrified Forest" of Arizona, really a series of petrified forests, lies a short distance south of Adamana, on the line of the Santa Fé Railway. There are four "forests," included in a government reservation called "Petrified Forest National Monument," created by presidential proclamation in 1906. The name "forest" is not strictly appropriate, for the petrified tree trunks are all prostrate and are broken into sections. The logs are the remains of giant trees that grew in Triassic time, the age of reptiles. The trees were of several kinds, but most of them were related to the Norfolk Island pine, now used for indoor decoration. Doubtless they in a near-by region and, after falling, drifted down a watercourse and lodged in some eddy or a sand bank. Later they were buried by sand and clay, finally to a depth of several thousand feet. The conversion to stone was effected by gradual replacement of the woody material by silica in the form called chalcedony, deposited by underground water. A small amount of iron oxides deposited at the same time has given the brilliant and beautiful brown, yellow, and red tints which appear in much of the material.

Some of the tree trunks are 6 feet in diameter and more than 100 feet in length. In the first forest there is a fine trunk that forms a natural bridge over a small ravine, the water having first washed away the overlying clay and sand and then, following a crevice, worked out the channel underneath. The length of this log is 110 feet, and the diameter 4 feet at the butt and 1½ feet at the top.

The petrified woods are beautiful objects to study. When thin slices are carefully ground down to a thickness of 0.003 inch or less and placed under the microscope they show perfectly the original wood structure, all the cells being distinct, though now they are replaced by chalcedony. By studying the sections F. H. Knowlton, of the United States Geological Survey, Department of the Interior, has found that most of these araucarian trees were of the species *Araucarioxylon arizonicum*, a tree now extinct. It is known to have lived at the same geological time also in the east-central part of the United States, where the remains of some of its associates have also been found. These included other cone-bearing trees, tree ferns, cycads, and other gigantic horsetails, which indicate that at that time, the rainfall was abundant.

The Protection of Iron by Electroplating. O. P. WATTS and P. L. DE VERTER. (*Proceedings of the American Electrochemical*

Society, September 28–30, 1916.)—Although nickel-plated iron is satisfactory for use indoors, when exposed to the weather it almost invariably rusts. Brass-plated steel is extensively employed for the cheaper grades of builder's hardware, but it is even more unsatisfactory than nickel-plate for out-of-door use. An electro-deposit of zinc on steel or iron is the only one that will withstand the atmospheric conditions for any reasonable length of time, and a demand is now being made for hardware that has received an electro-deposit of zinc before being plated with any other metal for ornamental purposes, such as nickel, copper, brass or bronze. The double coating gives good service and is the only satisfactory one for hardware which is exposed to the weather.

The superior protective action of electro-galvanizing in comparison with deposits of other metals on iron is well recognized. This has generally been ascribed to the voltaic action; whenever a hole is broken or worn through the plating a voltaic cell is formed between the metal coating and the exposed iron. If the coating consists of a metal which is electro-positive to iron, the latter is cathode and is protected from corrosion, but if the coating is electro-negative to iron this becomes anode, and is corroded worse than if the protective coating were entirely absent. Tables of potentials of the metals show that, of the metals that can be satisfactorily plated out of an aqueous solution, only zinc and cadmium are electro-positive to iron. Since cadmium is not used for plating on account of the expense, zinc remains as the only electroplate which can protect iron by voltaic or galvanic action. Theory and practice appear to be in harmony. Galvanic action requires that two unlike conductors be in electric connection with each other and with an electrolyte. So long as the iron is completely covered by the electroplate there is no opportunity for voltaic action, either corrosive or protective, and, so far as rusting of iron is concerned, it is immaterial what metal constitutes the coating. The protection of iron by deposits of zinc and its universal rusting when plated with other metals seems to indicate that electro-deposits of zinc are less porous than those of other metals, or that in the thickness used commercially all electro-deposits are porous, or on exposure soon become so, and thus the superior protection of zinc is due solely to its galvanic action.

The Sharpness of Photographic Negatives for Enlarging. E. CONSTET. (*Revue Generale des Sciences,* vol. 27, No. 6, March 30, 1916.)—There is too widespread error that the want of sharpness in the photographic image from very rapid gelatino-bromide emulsions is caused by the grain of the plate. It is true that if it is a question of enlarging an image 150 times, special emulsions of collodion and albumin must be employed. With these the grain only becomes observable with a magnification of 200 diameters, and at such magnifications it is only with a highly corrected lens and most precise

mounting of the apparatus that a sharp image can be secured. In the usual operations of photographic enlargement, however, a magnification of more than four diameters is seldom required.

In general terms, fast plates produce images with a grain less fine than slow plates. When the emulsion is prepared at as low a temperature as will insure the dissolution of the gelatin, it is quite transparent but very insensitive. As the emulsion is heated to increase its sensitiveness, it is seen to become more and more opaline, and a microscopic examination shows that the bromide of silver flocculates in grains of increasing volume. There is, however, no necessary relationship between the sensibility of the emulsion and the size of the grain, and the majority of manufacturers have succeeded, by processes more or less secret, in preparing rapid emulsions with a relatively fine grain. For example, among the products of the Lumière works, the "sigma" plate has three times the speed of the "blue label" plate, and yet the grain of the former is notably finer and more uniform than that of the latter. The "violet label" plate has seven times the sensitiveness of the blue label plate, nevertheless its grain is comparable in fineness with the sigma plate. The grain of the sigma plate is minute enough to define details one-fortieth of a millimetre, and with an enlargement of four diameters the sharpness of the image will be the order of one-tenth of a millimetre (about 0.004 inch). In practice, a departure from precise definition from two to two and one-half times this value is admissible. It is therefore not in the grain of the emulsion that the cause of poor definition in enlarging must be sought, but in the defects of the optical system and its mounting and to the treatment of the plate in the developing process.

Three Types of Lenses. C. W. PIPER. (*The British Journal of Photography*, vol. lxiii, No. 2937, August 18, 1916.)—The names of lenses are very numerous, but these names by no means represent different types. Broadly speaking, lenses may be divided into three classes—the portrait, rapid rectilinear, anastigmat classes—but, though this classification may seem quite familiar, it is not certain that the essential differences are generally understood. These differences mainly consist in varied degrees of correction, and the points of chief importance to the user are not the particular aberrations that are corrected, but the varying behavior of the three classes at large and small apertures and over large and small fields. It must be recognized that photographic optics has not yet reached such a stage of perfection as to permit the production of a lens that will work equally well at large or small apertures over either large or small areas. In every case there is a certain amount of compromise, and the correction for a large aperture involves the sacrifice of some other quality, as does also the production of good definition over large fields.

Taking the portrait type of lens first, the early specimens were essentially lenses corrected for very large apertures but over very small fields. At full aperture they may produce the most exquisite definition over an area not much bigger than a postage stamp, but give very inferior results over a larger area. Obviously such lenses may be of extreme value for certain work, and astronomers in particular are always glad to come across a fine specimen of the early type of Petzral portrait lens that possesses these qualities, for the central definition excels anything that can be secured with modern photographic lenses. This particular quality is, however, by no means necessary for portraiture; hence in modern types of portrait lenses some of the central definition has been sacrificed for the purpose of getting better definition over a larger area. The alteration is one of degree only, and so the portrait lens is still essentially a lens that will work at a very large aperture, but will cover with good definition only a very small area or angle.

In the next type of lens, more or less accurately designated "rapid rectilinear," the most essential difference is a reduction of aperture and the power of covering a bigger field. While a 6-inch portrait lens will sharply cover only the central part of a quarter-plate, the rapid rectilinear at f/8 should cover the whole sharply to the corners. This represents about the most that can be expected from rapid rectilinear lenses, and, while the lenses of the same or similiar type have been issued with f/6 apertures under various names, they will not cover such large plates. The best of these f/6 lenses form types intermediate between the rapid rectilinear and the portrait type, while the worst are simply rapid rectilinear lenses fitted with an aperture that is too large to permit of good definition anywhere.

Next is the anastigmat type. This is essentially a lens that at large aperture will cover a large area, but, to attain this very useful quality, again sacrifices have to be made, the chief of which usually is the perfection of definition at small aperture. At first sight this seems a serious matter, but a little consideration will show that it is one of small moment so long as large apertures are in use. The small aperture forms only a small portion of the large one, and the imperfectly corrected area of the lens in use with the small aperture plays a very small part in the formation of the image when the large aperture embracing the more perfectly corrected and much larger areas remote from the centre are used. There is also a certain amount of compromise as regards the definition in the area covered. Perfect definition cannot be secured over the whole area, and, as a rule, the best definition will lie at the centre and in a circular zone somewhere between the centre and the margins of the disk covered. The chief virtue of the anastigmat lens is that it will cover a larger area than either the portrait or rapid rectilinear types at a large aperture. If a large aperture is not wanted, the rapid rectilinear will work almost as well, and, in fact, will fulfil most of the requirements of the average photographer. On the other hand, if a very

narrow angle alone is to be covered, a portrait lens will work as well as an anastigmat, and probably at an even larger aperture. The anastigmat is the most universal of the three types, as it will do all that the other two will do, but for a great deal of ordinary work it is by no means essential.

Belt Conveyors. R. TRAUTSCHOLD. (*The Engineering Magazine,* vol. li, No. 5, August, 1916.)—Material supplied in an adequate and continuous stream can be handled more expeditiously by the belt conveyor than by other form of material-handling equipment. For handling loose material a troughed belt is required, and, though the load that can be supported by a foot of belt is not great, the capacity of even a narrow belt is suprisingly high, owing to the speed at which a belt may be run. For instance, under perfect loading conditions, a belt conveyor only 12 inches wide can handle nearly 90 tons of sand per hour, while one 36 inches wide has a capacity of 800 tons per hour when run at a speed of 375 feet per minute.

Considering a specific belt conveyor installation, one handling 85,000 tons of fine coal per year may be taken as typical and well illustrating the economic value of the device. Such a conveyor, 500 feet long, elevating the load 30 feet in its travel, and distributing it to an overhead bunker 100 feet in length, would not be an unusual installation. With power delivered to the conveyor drive costing 2 cents per horse-power, the net operating cost per ton, including all charges, is 1.957 cents with pin-bearing idler and 1.629 cents with roller-bearing equipment.

Resharpening Hack-saw Blades. ANON. (*The Iron Age,* vol. 98, No. 15, October 5, 1916.)—The Wardwell Manufacturing Company of Cleveland, Ohio, has brought out an automatic power hack-saw blade grinding machine which is said to be the first machine of the kind ever placed on the market. The machine is claimed to be extremely simple and a continuous stream of blades can be fed through it at a rate of 65 teeth per minute. This means that 14 to 18 blades, 18 inches in length can be resharpened in an hour. The blades are sorted by the operator into groups of the same width and pitch. Any width or length of blade with teeth up to as fine as 33 per inch can be resharpened, and it is claimed that they may be re-sharpened six or eight times or more, depending on the material being cut. It is stated that the actual cost of resharpening one blade does not exceed 2 cents, and that it will effect great economies to users of power hack-saw blades who now discard those blades as soon as they become dull.

Filling Acetylene Tanks. ANON. (*Acetylene Journal,* vol. xviii, No. 4, October, 1916.)—It is such a simple matter to use acetylene when the supply is obtained from a Prest-O-Lite tank that

few persons are aware of the involved processes that render such simplicity possible. Perhaps the most important of these is that unless the charging is carried out in the right way, the operation is attended with great danger of explosion. Most writers on the subject have been content to explain that actually only a very small quantity of the gas exists in the tank at any time, this being retained in the free space at the end nearest the valve, while the remainder of the tank is filled with discs of asbestos, or similar material, which is saturated with a liquid (acetone) having the property of dissolving no less than 25 times its own volume of acetylene for each atmosphere of pressure. There is no risk in handling or using such a tank that has been properly charged, for the reason that the volume of gas present is so small as to involve little chance of developing dangerous pressures even with a considerable rise in the temperature. The safety of the system, however, depends entirely upon proper charging. If the gas is not properly purified and dried the absorbent packing may be fouled and clogged, while the liquid may become polluted, the result being that the absorbing properties of the liquid are greatly reduced.

The gas formed in large generators at extremely low pressure, is first washed in "scrubbers" to remove soluble impurities, such as ammonia, after which it passes to one or more dryers to remove the surplus moisture. Then it is treated to remove such foreign compounds as phosphine and sulphuretted hydrogen, again dried and finally cleaned to remove any particles of lime dust. All these operations are performed at low pressure for the very good reason that free acetylene, even when unmixed with air, is subject to decomposition with explosive violence when subjected to pressures exceeding a gauge pressure of 15 pounds per square inch. After purification, the gas is raised to the charging pressure of 250 pounds by means of a "three-stage" compressor that is thoroughly water-cooled and equipped with a circuit breaker and contact gauge. The pressure is thus "stepped up" without permitting the temperature to rise above a safe amount at any time. In charging the cylinders, as well as in raising the gas to the necessary high pressure, the tanks are carefully maintained at a fixed temperature. From 10 to 20 hours are required to complete the operation, in order that the liquid in the tank may absorb in solution its full quota of gas. A check on the amount of gas absorbed is obtained by weighing each of the cylinders before and after charging.

Acid-Resisting Alloys. W. C. CARNELL. (*The Journal of Industrial and Engineering Chemistry*, vol. viii, No. 10, October, 1916.)—A process that is a success in the laboratory will be a success in the factory if conditions are duplicated. Platinum and glass are available in the laboratory, but may be prohibitive in the factory. The branch of the chemical industry that has suffered most

for materials for the construction of apparatus is the mineral acids division. For many years various metals and alloys were offered for which more or less acid-resisting properties were claimed. They had their uses, but as complete acid-resisting materials they were not successful.

The real dawn of an acid-resisting alloy came with the use of "silicon-iron" alloy. In May, 1912, the first silicon iron alloy in the United States was put on the market under the name "Duriron" by the Duriron Castings Company of Dayton, Ohio. In 1913 the American rights for "Tantiron" were acquired by the Bethlehem Foundry and Machine Company, of South Bethlehem, Pa. Both of these alloys are characterized by a content of about 14 per cent of silicon, though the amounts of other components are not identical. They both have a melting point of about 2500° F. and a tensile strength 5 per cent less than cast-iron. Silicon iron alloy as exploited under the above names is very resistant to all strengths of sulfuric acid, and apparatus made of this alloy is used in all forms of concentrating vessels and cooling devices for the concentration of sulfuric acid. Silicon iron alloy castings have extensively replaced stoneware parts for the manufacture of nitric acid. It can be cast into all the different forms required for nitric acid apparatus and is resistant to the acid of various strengths. Castings can be made as readily and quickly as those of cast-iron, though it cannot be cast in rectangular shapes or flat surfaces. Since its introduction, new chemical processes have been started which were impossible before, because of lack of suitable apparatus. Silicon iron alloy is being improved upon rapidly and the time does not seem far distant when all sorts of vessels will be made of this or similar alloy that will give to the chemical industry the ideal non-corrosive material that may be fabricated into all the shapes peculiar to the needs of the industry.

The Small Geared Steam Turbine. ANON. (*Power,* vol. xliv, No. 15, October 10, 1916.)—When Professor De Laval first introduced his simple impulse turbine, he found it necessary to run the turbine at very high speeds to secure good economy. But in order to adapt the turbine to the electric generators of that day, it was found necessary to introduce a reduction gear between the turbine and generator. This method is still used by the builders of the De Laval turbines on small units. The other types of turbines that were introduced at nearly the same time or later, such as the Parsons, the Rateau and the Curtis, were at first designed to run at much more moderate speeds, so that they could be direct connected to electrical machinery or to pumps without the use of intermediate gearing. In a late development of the simple impulse type, the steam is redirected so as to impinge on the blades a number of times and thus permit lower wheel speeds and direct connection.

Quite recently one of the largest turbine builders in this country has developed a new line of simple impulse turbines to be run at speeds of 6000 to 7000 revolutions per minute and to be connected through gears to the machines which they drive. These units have met with a considerable measure of success and are increasing rapidly in popularity. The most important consideration in returning to the geared unit after the development of the slow-speed repeated-flow simple impulse turbine is that of economy. High-speed geared units are said to show a gain of economy of 15 per cent. over the repeated flow type, slower-speed direct connected units.

Some difficulty was experienced with the wearing of the teeth of the earlier gears, but this has been overcome by accurate workmanship and suitable lubrication. The Westinghouse-MacAlpine floating-frame was introduced to insure proper contact and thus avoid cutting. At about the same time, however, gears were used on the large Parsons turbines without special provision for adjustment other than accurately made bearings which were kept well lubricated. This apparently has been all that is necessary, for the newer American types have proved satisfactory without special devices to maintain alignment. The early gears were usually of bronze. High-carbon steel is now used to a great extent and seems better suited to the purpose.

The small geared-turbine provides a cheap light-weight and economical unit. It will not cause any revolution in power plant practice but it will gradually find its place as its advantages and its adaptability to special conditions and particular uses are recognized.

The Wire Drag in Hydrographic Surveying. E. L. JONES. (*U. S. Coast and Geodetic Survey,* Serial No. 47, Elements of Chart Making, 1916.)—Surveying our waters for navigational charts has in the past largely been done by means of sounding with the lead line, and for the reason of the limitations of that method the information as to the form of the bottom so obtained is restricted to points more or less separated. In other words, the hand lead, weighing about 12 pounds, is attached to a line and cast overboard at various intervals to ascertain the depth of water, and does not give a complete and final knowledge of certain water areas. As surveys by the lead-line method failed frequently to reveal even an indication of the presence of rocky pinnacles, ledges, bowlders, coral reefs, etc., it became more and more evident that some new device especially adapted to the requirements of such localities was urgently needed. For this purpose the wire drag was adopted.

From its crude original form there has been rapidly developed, by the Coast and Geodetic Survey, an apparatus which in practice gives results that are final. It consists of a horizontal bottom wire, supported at intervals by adjustable upright cables suspended from buoys on the surface. These uprights can be lengthened or short-

ened for various required depths, and to maintain the bottom wire at a given depth below the surface of the water by making allowance for the rise and fall of the tide. The uprights are maintained in a nearly vertical position by means of weights attached to their lower ends. Intermediate between the uprights, wooden floats are attached directly to the drag wire to prevent sagging between the uprights. The end weights and buoys are larger than the intermediate, and to them the towing gear from the launches is attached.

In operation the drag is extended by directing the course of the launch outward from the middle of the drag as well as forward along the center of the area to be swept. An interesting feature of the apparatus is the signalling system between the end launches, made necessary by the great length of the drag which is sometimes four or five miles long. Upon meeting an obstruction in its course, the drag at once indicates the obstruction and points out its location. As soon as the drag wire touches an obstruction, there is a marked increase in the tension on the drag, which is noted immediately on the spring balance to which the tow line is attached; and the position of the shoal is shown by the buoys which line up between the obstruction and the launches. A buoy is then placed at the intersection of the two lines of drag buoys, the drag is cleared and moved ahead on its course and the detailed examination of the spot is then made by a sounding party in a small tender or sounding boat.

Characteristics of Small Dry Cells. C. F. BURGESS. (*Proceedings of the American Electrochemical Society*, September 30, 1916.)—The flash light industry has been greatly stimulated by the development of the high efficiency miniature tungsten lamps, and of an influence equal in importance is the decided improvement in the qualities of the battery. The two most important characteristics by which the value of flash light batteries may be determined are ability to furnish light over a period of time, or its capacity, and its ability to withstand deterioration when not in use, or its shelf life. Other characteristics of importance are voltage, recuperation, uniformity, size, cost. Since by far the most important use of small cells is for flash light service, the tests aim to parallel as far as practicable this type of service.

The two most important characteristics by which the value of flash light batteries may be determined are its capacity, and its shelf life. The standard method of capacity test which has been used in the laboratories of several manufacturers is to adopt a fixed standard of resistance through which the individual cell is discharged, and noting the length of time on discharge required for the cell to drop to a certain voltage. It has been found that four ohms per cell of battery used is close to the average resistance of the common sizes of standard lamps, and this is adopted as the standard. There is room for argument as to what voltage should be taken as that

at which the battery becomes useless. With the pressure at one-half volt per cell the light is sufficient to read a clock dial but not for general flash light service. Accordingly, 0.5 volt per cell has been taken as the standard limiting value or "end point." It appears to be a general practice among manufacturers to guarantee their batteries against a falling off in open circuit voltage. Many tests and long experience indicate that a far better method of determining the deterioration going on within the cell is measured by the short circuit flash which the cell gives when connected momentarily to the ammeter. While the reading it not strictly proportioned to the ampere-hour capacity, it is nevertheless a far better indication than the dropping of open-circuit voltage.

Small cells are found on the market in a great variety of sizes and forms of battery. The most common form is the two-cell and three-cell tubulars for use in metal and fibre cases. Of almost equal importance is the two-cell and three-cell battery of smaller dimensions, the cells being placed side by side for use in flat cases and commonly designated as the "case type." These cells vary in size from 9/16 to 1¼ inches in diameter and from 1 $^9/_{16}$ to 2¼ inches in length. They have a voltage of 1.45 to 1.55 or even 1.6. Capacity tests show that the best cells have a capacity about 100 per cent. above the poorest, and durability tests show much greater differences. If a manufacturer could discover some method of construction so that each cell would be exactly like the best which he can produce, it would be an important achievement in the improvement of quality.

Brick Roads for Country and City. ANON. (*Professional Bulletin, U. S. Department of Agriculture.*)—Country roads paved with vitrified brick are becoming quite common in many of our States, according to the professional bulletin "Brick Roads," recently issued by the Office of Public Roads and Rural Engineering, U. S. Department of Agriculture.

The purpose of the new bulletin, which can be had free, so long as the Department's supply lasts, by road engineers, supervisors, and others contemplating the construction of brick roads, is to make clear certain important essentials in the choosing of brick for a pavement and in laying it so that the highway will endure. The principal advantages which brick roads possess, according to the authors, may be stated briefly as follows: (1) They are durable under practically all traffic conditions; (2) they afford an easy traction and moderately good foothold for horses; and (3) they are easily maintained and kept clean. The principal disadvantage is the high first cost. The defects which frequently result from lack of uniformity in the quality of brick or from poor construction are usually to be traced indirectly to an effort to reduce the first cost or to a popular feeling that local materials should be used, even when of inferior quality.

The first brick pavement constructed in this country, it is stated, dates back to 1872, and Charleston, W. Va., has the distinction of being the first American city to employ this product for paving. For a number of years after its introduction, however, the use of paving brick was confined principally to city streets, and, owing to the frequent inferiority in the quality of the brick and the lack of care in construction, very few of the early pavements proved satisfactory. Even now, after the experience of forty years has demonstrated that it is entirely practicable to construct satisfactory brick pavements when proper care is exercised, and that much waste results from the use of poor materials or faulty construction, instances can still be frequently found where comparatively new pavements have wholly or partially failed from causes which might easily have been prevented.

The selection of the brick is one of the most essential features, for the success or failure of such pavements depends, to a large extent, on the way in which the brick will withstand the kind of traffic for which the road is designed. The engineers point out that it is very poor economy to use a locally manufactured brick unless this brick is of a high standard. Color, specific gravity, absorptive power, or even the crushing strength, of brick are not necessarily reliable tests. In general, of course, the brick should be uniform in size, perfect in shape, free from ragging and deep kiln-marks. Each brick should be homogeneous in texture and free from objectionable seams. Fire cracks should be limited in number and extent, and the entire brick should be vitrified and should contain neither unfused nor glassy spots. Even field inspection and laboratory analysis, unless conducted by those especially experienced, however, may prove of little value.

According to the bulletin, the test upon which highway engineers appear to place most reliance is the "rattler" or abrasion test. In this test 10 dry bricks are placed in a rattle barrel with 10 cast-iron spheres 3¾ inches in diameter and weighing 7.5 pounds each, and enough spheres 1⅞ inches in diameter and weighing 0.95 pounds each to make up 300 pounds of metal. The loaded rattle barrel is then revolved continuously 1800 times at a speed not lower than 29½ nor exceeding 30½ revolutions per minute. When the test is over the results are reckoned in terms of the loss in weight sustained by the brick. No piece of brick which weighs less than one pound is considered as having withstood the test.

Good paving brick under this test ordinarily will lose from 18 to 24 per cent. of their original weight. The specialists point out, however, that it is advisable to require a minimum as well as a maximum loss which any sample may sustain. This is necessary for insuring against too much variation between the softest brick and the hardest brick which may be supplied.

The remainder of the 40-page bulletin is devoted to detailed descriptions and diagrams, showing proper methods of construction of brick roads, including the preparation of the roadbed, the con-

struction of the foundation or base, the laying of the brick, the construction of curbing, expansion cushions, and the final finishing of the pavement. The paper also includes a chapter on cost of brick pavements. Special emphasis is laid on the maintenance of these roads and the need for proper engineering supervision in their construction. An appendix is devoted to typical specifications for constructing brick roads.

The Possibilities of Developing Super-Refractory Materials for Incandescent Lighting. F. A. FAHRENWALD. (*Proceedings of the American Electrochemical Society*. September 28–30, 1916.)—It would seem to be generally conceded by electrical and illuminating engineers, that the upper limit of temperatures at which incandescent lamps may be used is fixed by the practical operating temperature of the tungsten filament. The combinations of metallic with non-metallic elements have been extensively studied, and the general properties of these compounds are well defined. No substances of this type, however, have been found satisfactory in this connection. Although the oxides of calcium, magnesium, and similar metals have found wide application in cases where heat can be applied externally, none of these can rival the tungsten filament for illuminating purposes. The conditions under which electrically heated filaments may be operated, however, allows another field to be considered—one that has as yet received little attention with this end in view—that of inter-metallic combinations.

Inter-metallic Compounds are almost invariably brittle, and such a compound if present in sufficient quantities in an alloy in which it is insoluble destroys its ductility. If a compound more refractory than either component is formed (which is a common occurrence), and if this be soluble in the more refractory component, then quite ductile refractory solid solutions are possible. Many inter-metallic compounds possess melting points several times as high as either component, which is also true of non-metallic compounds. Many of these compounds are very stable at their melting temperature if inclosed in a proper atmosphere. In many cases the melting point of a metal is lowered but very little by the solution in it of another metal, and if such a condition should accompany lowered vapor pressure, a greater thermal stability will result, thus enabling higher temperatures to be employed than are now practicable. Several series of alloys in which compounds occur that possess melting points above those of their component metals will serve as examples of the type of super-refractory compounds that may be developed by alloy research in the field of refractory metals. The mercury-sodium series is a good example, at low temperatures, of this type of alloy. Mercury melts at —38.6° C., Sodium at 97.5° C., but an alloy of the two containing these elements in the proportions represented by the formula $Na\ Hg_2$ melts at 360° C. In the zinc-tellurium series,

the compound of the formula Zn Te melts above 1200 C., while the melting points of the pure elements themselves are 421° C. and 419°C. respectively. At still higher ranges, in the nickel aluminum series, the compound Ni Al does not fuse below 1640 C. nearly 200°C. above the melting point of nickel.

It is not at all improbable that an investigation of the more refractory metallic alloys will reveal a binary series possessing a melting point curve with a maximum similar to that shown on these three typical examples. Even if this should extend only a few hundred degrees above the melting point of tungsten, the fact that the lighting efficiency does not vary directly, but as a higher power of the temperature employed, would make a material of this nature of very great value.

Melting Aluminum Chips. H. W. GILLETT and G. M. JAMES. (*U. S. Bureau of Mines*, Bulletin No. 108, October, 1916.)—The recovery of metallic aluminum in melting down chips such as are obtained in the automobile factories in machining aluminum castings commonly amounts to only 60 per cent. of the metal available, and as a 90 per cent. recovery is commercially possible, the preventable loss is of considerable magnitude. The main cause for low recoveries is apparently the difficulty of getting the tiny globules of molten metal, resulting from the fusion of the very fine chips, to coalesce when covered with oxide and dirt. As, on an average, 15 per cent. of the weight of aluminum castings for automobiles is machined off as chips, the possible saving to the automobile manufacturer is much greater than the cost of adopting careful methods of recovery.

Two methods of melting can be successfully used to promote coalescence. In one method the chips are kept just above the fusion point and the globules are made to coalesce by hand puddling, which breaks through the skin and makes the globules unite. In this method, the melting is best done in an iron pot heated by oil. The other is by the use of a flux to dissolve off the skin of dirt and oxide, producing clean globules which can unite. The flux suggested is 85 per cent. common salt, and 15 per cent. fluorspar used in large amount (20 to 30 per cent. of the weight of the chips) and mixed with the chips before charging. Much higher temperatures are required by this method than by the puddling method, so the iron pot furnace is not practicable and melting is best done in graphite crucibles or in a reverberatory furnace. The flux method does not require the constant hand puddling of the other method.

Rectangular Gas Mains. C. N. GREEN. (*American Gas Light Journal.* Vol. CV. No. 17. October 23, 1916.)—During Rapid Transit subway construction, and the attendant restoration of subsurface structures in New York City, one of the many interesting problems encountered, taxing the skill and ingenuity of the designer,

has been the restoration of pipe lines within the restricted space remaining available. In the Southern Boulevard, Bronx Borough, the Subway passes under the Port Morris Branch of the N. Y. C. & H. R. R. R. with no room for pipes between the subway roof and the railroad tracks. The railroad tracks are depressed and the Southern Boulevard crosses them on a bridge made of 24-inch I-beams and buckle plates. The buckle plates are laid on the top flange of the I-beams and support the street. There were not sufficient spaces between the I-beams to permit of manifolding the gas mains, and the distance from the street surface to the under side of the bridge would not permit the full sized main to be restored.

The gas mains were respectively 20 and 30 inches in diameter. Steel boxes were designed, one 16 x 21 inches in rectangular section, and the other 16 x 43½ inches, inside dimensions. The boxes were made of ½ inch plates riveted to ½ inch angles at the corner of the box, the angles were placed inside the box. Splices were lap riveted and all joints were caulked inside and outside. A special section was made which is rectangular at one end to fit the box and at the other end round to fit the bell of the regular main. The larger box is stiffened with a longitudinal I-beam to carry the street load. Both boxes were surrounded with concrete to reduce the possible leakage of gas to a minimum.

Humane Furnace Stoking. ANON. (*Power,* Vol. 44, No. 16. October 17, 1916.)—When a power plant is laid out for a building, the boilers and engines are frequently put in almost anywhere that they will fit, and apparently no thought is given to the probable working conditions of the men who will be employed to operate them. Frequently the furnaces are equipped with mechanical stokers, and the firemen are made to throw the coal from the floor into the hoppers—a man-killing job to say the least. In a large power plant visited recently, the furnaces of the boilers were hand fired, burning buckwheat fuel. The grates were twelve feet long, requiring a man of very ample strength to cover them. Every ounce of coal burned under these large boilers had to be shoveled into the furnace from piles in the boiler-room floor, the supply coming from an overhead bin. Towards the end of the eight-hour shift the plant suffered a marked diminution in steaming capacity, the grilling labor proving more than human strength could endure.

An easy method of firing small sized anthracite coal has been adopted by the Harrisburg Light and Power Co., Harrisburg, Pa. Here the coal supply comes from an overhead bunker, but instead of being delivered in a pile on the floor, it is discharged into the hoppers. The firemen pull a lever to let down the coal, open the firing gate, and merely spread the fuel with a light hoe, operations requiring about one-tenth the normal labor necessary with the shovel. At the end of the shift the men are not exhausted, and more than that, fewer men are required in the boiler-room force.

Use of Diatomaceous Earth in Sugar Refining. ANON. (*U. S. Geological Survey Press Bulletin* No. 297, November 1916.)—Diatomaceous earth, which is made up of remains of minute aquatic plants, is a light earthy material resembling chalk or clay. The hardness, the minute size, and the angular shape of its grains make it an excellent metal-polishing agent, and heretofore it has been largely used as an abrasive in the form of polishing powders and scouring soaps. Of late, however, according to the United States Geological Survey, Department of the Interior, the uses of diatomaceous earth have been considerably extended. It is used by sugar refiners for filtering or clarifying; as an insulating packing material for safes, steam pipes, and boilers; and as a fireproof building material. In the United States it is used in the manufacture of records for talking machines. In Europe it has been used in preparing artificial fertilizers and in the manufacture of water glass, cements, artificial stone, paper, sealing wax, fireworks, papier-maché, and other articles. A total of 4593 tons of diatomaceous earth was produced and sold in the United States in 1915.

A New Size of Camera. ANON. (*Camera Craft*. vol. xxiii. No. 11, November, 1916.)—The 8 x 10 size of plate or picture has the same proportion as the 4 x 5, a proportion that is being supplanted in favor by the post card size in the latter case, and in the former will no doubt find a strong competitor in the new 7 x 11 size issued by the Eastman Kodak Company. This is perhaps the most pleasing proportion that could be given the view photographer as it is a little shorter form of the parallelogram than the popular post card size and a little longer than the 5 x 7; it is, in fact, practically midway between the two. For group work the new size is just right, while for view and landscape work the unnecessary sky space that is nearly always in evidence in the 8 x 10 print is transferred to the ends where more room is generally wanted. Best of all the new form is much better suited to upright subjects such as tall buildings and the like. In addition the picture looks larger and the particular proportion will almost invariably show either much more of the subject matter or larger images of the objects photographed than will the 8 x 10 size.

Kauri Gum Oil—New Zealands' Substitute for Gasoline. ANON. (*Scientific American*, vol. cxv. No. 19, November 4, 1916.)—A company has been organized to extract Kauri gum oil from peat taken from the swamps in the northern part of North Island, New Zealand where Kauri gum has been mined for years. Some years ago a company was formed for this purpose and machinery installed and the plant was worked for some time, but not with favorable results, since the methods adopted and the machinery installed were not well suited for the work, so it was finally given up for a time.

It is claimed that the peat yields 20 to 30 gallons per ton, of which about 25 per cent. resembles gasoline or benzine, which is being used for motor cars and launches at this time. The remainder contains some 28 different varieties of heavy oil, some of which make exceptionally good varnishing material. It is further stated that in the north of the island are found extensive beds containing much fine kauri gum particles, and rich in materials producing this kauri gum oil, as well as kauri gum that may be extracted fom the deposits.

Surface Tension Jet Recorder. ANON. (*Electrical World*. vol. 68, No. 20, November 11, 1916.)—Valdemar Poulson, the Danish scientist, has evolved an instrument the action of which is based essentially on the alteration of the surface tension of a mercury jet by direct, alternating or even high-frequency currents. In patent No. 1,198,270, two applications of the principle are shown. In one, the current in the signal circuit causes the mercury jet to be deflected and in the other, the jet is differentially broken up into separate globules by the current, and thereby is made to operate a relay in accordance with the received impulse. The apparatus consists of a jet of liquid (strong or weak electrolyte or preferably mercury or a liquid metal alloy), which while it is still coherent and not resolved into separate drops, is in contact with a substance which forms with it a system consisting of an electrolyte and an electrode through which signal currents are led by means of another electrode.

In one form a tube of glass or iron, in which is found mercury, under suitable pressure produces a jet only a fractional part of a millimeter in diameter. The still coherent part of the jet touches a piece of glass which is partly encompassed by a body of porous nature, kept moistened with a solution of caustic potash. Around the body is wound a platinum wire serving as a conductor and at the same time acting as one electrode, the mercury jet forming the other. As soon as an alteration in the potential difference between the wire and the mercury arises owing to signal currents, the coherent part of the mercury jet is altered so that the jet is bent aside. In a modified form the lower end of the tube has a moistened ring-shaped piece of bone arranged about it. Each signal current in the signal circuit causes the coherent part of the jet to vary its length. Thus during the passage of the signal currents through the signal circuits, the jet and the contact will alternately open and close the local circuit in which the latter is interposed.

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THE FRANKLIN INSTITUTE

ANNOUNCEMENTS

MEETINGS

COMMITTEE ON SCIENCE AND THE ARTS. First Wednesday of each month, 8 P.M. (except July and August).

BOARD OF MANAGERS. Second Wednesday of each month, 3.30 P.M.

INSTITUTE. Third Wednesday of each month (except June, July, August and September), 8 P.M.

SECTION MEETINGS. Thursday Evenings (except week of Institute Meeting), 8 o'clock. October 1 to April 30.

CHANGES OF ADDRESS

Members are particularly requested to inform the Secretary of changes of address.

OFFICERS FOR 1916

The Board of Trustees was formed in accordance with the following By-Laws passed in the year 1887:

> All Real and Personal Estate of the Institute which may hereafter be acquired by voluntary subscription or devise, bequest, donation, or in any way other than through its own earnings or by investment of its own funds, saving where the donors shall expressly provide to the contrary, shall be taken as acquired upon the condition that the same shall be vested in a Board of Trustees, who shall be appointed in the manner hereinafter indicated. Unless the title to such property shall be directly vested in said Board of Trustees by the donors, the Institute, by deed attested by the President and Secretary, which they are hereby authorized to execute and deliver, shall forthwith convey the same to said Trustees, who shall hold it in trust for the purposes specifically designated by the donors; or, if there shall be no specific designation, for the benefit of the Institute in the way and manner hereinafter provided, so that the same shall not, in any event, be liable for the debts of the Institute.

This method of separating the *body holding* the principal of the various funds from the Board of Managers, the *spending body*, is an original idea of The Franklin Institute and it is hoped it will appeal to friends who may desire to create funds to further the objects of the Institute, and the various branches of science in which they may be interested.

MEMBERSHIP.

Terms and Privileges.

THE MEMBERSHIP OF THE INSTITUTE is divided into the following classes, viz.: *Resident Members, Stockholders, Life Members, Permanent Members, Non-resident and Associate Members.*

Any one interested in the purposes and objects of The Institute and expressing a willingness to further the same may become a member when proposed by a member in good standing and elected by the Board of Managers.

TERMS.—Resident members pay Fifteen Dollars each year. The payment of Two Hundred Dollars in any one year secures Life Membership, with exemption from annual dues.

STOCK.—Second-class stockholders pay an annual tax of Twelve Dollars per share, and the holder of one share is entitled by such payment to the privileges of membership.

PRIVILEGES.—Each contributing member (including non-residents) and adult holder of second-class stock is entitled to participate in the meetings of The Institute, to use the Library and Reading Room, to vote at the Annual Election for officers, to receive tickets to the lectures for himself and friend, to attend the Section meetings and to receive one copy of the JOURNAL *free* of charge, except associate members, who may not take part in elections.

PERMANENT MEMBERS.—The Board of Managers may grant to any one who shall in any one year contribute to The Institute the sum of One Thousand Dollars a permanent membership, transferable by will or otherwise.

NON-RESIDENT MEMBERS.—Newly elected members residing permanently at a distance of twenty-five miles or more from Philadelphia may be enrolled as Non-resident Members, and are required to pay an entrance fee ot Five Dollars, and Five Dollars annually. Non-resident Life Membership, $75.00.

Contributing members, if eligible, under the non-resident clause, on making request therefor, may be transferred to the non-resident class by vote of the Board of Managers, and are required to pay Five Dollars annually.

ASSOCIATE MEMBERS.—Associate members are accorded all the privileges of The Institute, except the right to vote or hold office, upon the payment of annual dues of Five Dollars. This class of membership is limited to persons between the ages of seventeen and twenty-five years. Upon reaching the age limit they become eligible to the other classes of membership.

RESIGNATIONS *must be made in writing, and dues must be paid to the date of resignation.*

For further information and membership application blanks address the SECRETARY of THE INSTITUTE.

THE FRANKLIN INSTITUTE AWARDS

The following awards are made by, or on the recommendation of
The Franklin Institute
acting through its Committee on Science and the Arts:

THE FRANKLIN MEDAL
THE ELLIOTT CRESSON MEDAL
THE HOWARD N. POTTS MEDAL
THE JOHN SCOTT LEGACY MEDAL AND PREMIUM
THE EDWARD LONGSTRETH MEDAL OF MERIT
THE CERTIFICATE OF MERIT

The Franklin Medal

(Gold Medal and Diploma).—This Medal is awarded annually from the Franklin Medal Fund, founded January 1, 1914, by Samuel Insull, Esq., to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

The Elliott Cresson Medal

(Gold Medal and Diploma).—This Medal is awarded for discovery or original research, adding to the sum of human knowledge irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship. (See page xv.)

The Howard N. Potts Medal

(Gold Medal and Diploma).—This Medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products utilizing important principles or of superior excellence; and for papers of especial merit that have been presented to The Institute and published in its Journal.

The Edward Longstreth Medal of Merit

(Silver Medal and Diploma).—This Medal, with a money premium when the accumulated interest of the Fund permits, may be awarded for meritorious work in science or the arts; including papers relating to such subjects originally read before The Institute, and papers presented to The Institute and published in its Journal.

The Certificate of Merit

A certificate of merit is awarded to persons adjudged worthy thereof for their inventions, discoveries or productions.

The John Scott Legacy Medal and Premium

Is awarded by the Board of Directors of City Trusts of the City of Philadelphia, on the recommendation of The Franklin Institute. (For conditions see page xvi.)

The Boyden Premium.

Is to be awarded by The Franklin Institute under conditions detailed on page xvii.

Further information regarding the above awards may be obtained by addressing the Secretary of The Institute.

THE FRANKLIN INSTITUTE AWARDS

THE ELLIOTT CRESSON MEDAL

THE FRANKLIN INSTITUTE awards the ELLIOTT CRESSON GOLD MEDAL under the provisions of the Deed of Trust from ELLIOTT CRESSON of the City of Philadelphia, dated the Eighteenth day of February, 1848, on the recommendation of its Committee on Science and the Arts.

"This Medal and Diploma shall be awarded for discovery or original investigation, adding to the sum of human knowledge irrespective of commercial value; leading and practical utilization of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship."

For further information address the Secretary of THE INSTITUTE.

THE FRANKLIN INSTITUTE AWARDS

THE JOHN SCOTT LEGACY MEDAL AND PREMIUM

THE City of Philadelphia holds in trust under the legacy of John Scott, of Edinburgh, a sum of money the interest of which is to be used for the encouragement of "ingenious men and women who make useful inventions." **The legacy provides for the distribution of a Medal, inscribed "To the Most Deserving," and Money Premium in the sum of $20 to such persons whose inventions shall merit the same.** The examination of the inventions submitted for the Medal and Premium has been delegated by the Board of Directors of City Trusts, of the City of Philadelphia, to THE FRANKLIN INSTITUTE, and THE INSTITUTE, under the competent assistance of its Committee on Science and the Arts, undertakes to make investigations free of charge and to recommend for the award all meritorious inventions.

Applications should be addressed to the Secretary of THE FRANKLIN INSTITUTE, from whom all information relative thereto may be obtained.

Pursuant to the regulations for the award of the John Scott Legacy Medal and Premium, THE FRANKLIN INSTITUTE, of the State of Pennsylvania, has under consideration favorable reports upon the applications advertised in this JOURNAL. Any objection to the proposed awards, based on evidence of lack of originality or merit of the invention, should be communicated to the Secretary of THE INSTITUTE within three months of the date of notice.

THE FRANKLIN INSTITUTE AWARDS

THE BOYDEN PREMIUM

URIAH A. BOYDEN, ESQ., of Boston, Mass., has deposited with THE FRANKLIN INSTITUTE the sum of one thousand dollars, to be awarded as a premium to

"Any resident of North America who shall determine by experiment whether all rays of light,* and other physical rays, are or are not transmitted with the same velocity." :: :: :: ::

The following conditions have been established for the award of this Premium:

1. Any resident of North America, or of the West India Islands, may be a competitor for the Premium; the southern boundary of Mexico being considered as the southern limit of North America.

2. Each competitor must transmit to the Secretary of THE FRANKLIN INSTITUTE a memoir describing in detail the apparatus, the mode of experimenting and the results; and all memoirs received by him after the first day of January, one thousand nine hundred and sixteen, will, as soon as possible after this date, be transmitted to the Committee of Judges.

3. The Board of Managers of THE FRANKLIN INSTITUTE shall, before the first day of January, one thousand nine hundred and seventeen, select three citizens of the United States o competent scientific ability, to whom the memoir shall be referred; and the said Judges shall examine the memoirs and report to THE FRANKLIN INSTITUTE whether, in their opinion, any, and, if so, which of the memoirs is worthy of the Premium. And, on their report, THE FRANKLIN INSTITUTE shall decide whether the Premium shall be awarded as recommended by the Judges.

4. Every memoir shall be anonymous, but shall contain some motto or sign by which it can be recognized and designated, and shall be accompanied by a sealed envelope, endorsed on the outside with some motto or sign, and containing the name and address of the author of the memoir. It shall be the duty of the Secretary of THE FRANKLIN INSTITUTE to keep these envelopes securely and unopened until the Judges shall have finished their examination; when, should the Judges be of opinion that any one of the memoirs is worthy of the Premium, the corresponding envelope shall be opened, and the name of the author communicated to THE INSTITUTE. The sealed envelopes accompanying unsuccessful memoirs will be destroyed unopened, in the presence of the Board of Managers.

5. Should the Judges think proper, they may require the experiments described in any of the memoirs to be repeated in their presence.

6. The memoirs presented for the Premium shall become the property of THE FRANKLIN INSTITUTE, and shall be published as it may direct.

The problem has been more specifically defined by the Board of Managers, as follows:—

"Whether or not all rays in the spectrum known at the time the offer was made, namely, March 23, 1859, and comprised between the lowest frequency known thermal rays in the infra-red, and the highest frequency known rays in the ultra-violet, which in the opinion of the Committee lie between the approximate frequencies of 2×10^{14} double vibrations per second in the infra-red and 8×10^{14} in the ultra-violet, travel through free space with the same velocity."

***An award, made during the year 1907, covered the solution of the problem so far as the transmission of the visible and ultra-violet rays is concerned. It has been directed by the Board of Managers that the balance of the fund be retained, to be awarded to such person as shall demonstrate whether or not the infra-red rays are or are not transmitted with the same velocity as the other rays.**

THE FRANKLIN INSTITUTE AWARDS

JOURNAL CONTRIBUTIONS

By a resolution of the Committee on Science and the Arts, made October 5, 1910, all papers published in the Journal of The Franklin Institute will be subject to the award of one of the following Medals—

The Howard N. Potts Gold Medal

The Edward Longstreth Silver Medal

The merits of the several papers appearing in the Journal during any current year will be passed upon by a Special Committee appointed for the purpose.

R. B. OWENS,
Secretary